

FLOOD OF JANUARY 1982 IN THE SAN FRANCISCO BAY AREA, CALIFORNIA

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ADMINISTRATION

U.S. GEOLOGICAL SURVEY

Water-Resources Investigations Report 88-4236

Prepared in cooperation with the
NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION

1002-41



Sacramento, California
1989

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CONVERSION FACTORS

For readers who prefer to use metric and International System (SI) units rather than inch-pound units, the conversion factors for the terms used in this report are as follows:

<u>Multiply inch-pound unit</u>	<u>By</u>	<u>To obtain metric unit</u>
acre-foot (acre-ft)	1,233	cubic meter
cubic foot per second (ft ³ /s)	0.02832	cubic meter per second
cubic foot per second per square mile [(ft ³ /s)/mi ²]	0.01093	cubic meter per second per square kilometer
foot	0.3048	meter
inch	25.4	millimeter
inch per hour (in/h)	25.4	millimeter per hour
knot	0.515	meter per second
mile	1.609	kilometer
millibar (mb)	0.1	kilopascal
square mile	2.590	square kilometer

Degree Fahrenheit is converted to degree Celsius by the following formula:

$$\text{Temp. } ^\circ\text{C} = (\text{temp. } ^\circ\text{F} - 32) / 1.8.$$

Sea level: In this report "sea level" refers to the National Geodetic Vertical Datum of 1929 (NGVD of 1929)--a geodetic datum derived from a general adjustment of the first-order level nets of both the United States and Canada, formerly called Sea Level Datum of 1929.

FLOOD OF JANUARY 1982 IN THE SAN FRANCISCO BAY AREA, CALIFORNIA

By J.C. Blodgett¹ and Edwin H. Chin²

ABSTRACT

A major winter storm originating over the Pacific Ocean moved through central California in early January 1982. As much as 16 inches of rain fell in Marin County and 25 inches in the mountains bordering Santa Cruz County. Only local streams were affected by the storm because the convective process that normally produces heavy rainfall over large areas was absent. Instead, the storm of January 3-5, 1982, had a stable atmospheric structure, and the layer of moist maritime air was confined to altitudes between 50 and 700 feet; this phenomenon caused the rain to fall most heavily along the lower slopes of the coastal mountains.

As a result of antecedent rainfall, streamflow in the San Francisco Bay area exceeded normal from the end of October to the end of December 1981. For most streams, the January 1982 flood was the largest since the flood of December 1955, but it was not significantly large in comparison with historic peak-flow data. Damages associated with the storm were substantial, but flooding from stream runoff was not the major problem. Greater than normal antecedent rainfall, together with the prolonged heavy rain, liquified the super-saturated soil cover and caused numerous slope failures and debris flows on steep, unstable slopes. The median recurrence interval of the 1982 peak for 66 streamflow-gaging stations in the San Francisco Bay area is 10 years; for the 1955 flood, the median recurrence interval for 16 stations is 11 years. Unit peak runoff for streams in the study area was as much as 927 cubic feet per second per square mile (drainage area 1.09 square miles). Streams with highest unit peak runoff were in the Santa Cruz Mountains and North Bay subareas. Median recurrence intervals of flood volumes for durations of 1, 3, and 8 consecutive days during the January 1982 flood are 18, 11, and 8 years; these recurrence intervals are comparable to those of the December 1955 flood, which are 13, 16, and 14 years.

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INTRODUCTION

A major winter storm originating over the Pacific Ocean moved through central California in early January 1982. Prolonged heavy rain fell over the area around San Francisco Bay from late afternoon January 3 through early morning, January 5, 1982. The storm produced as much as 16 inches of rain in parts of Marin County and nearly 25 inches of rain in the mountains bordering the San Lorenzo River valley in Santa Cruz County. Large areas of Santa Cruz and Marin Counties had more than 6 inches of rain, as did smaller parts of San Mateo, Alameda, Contra Costa, Solano, and Sonoma Counties.

Many parts of the San Francisco Bay area (pl. 1) were affected by flooding and landslides. Effects of the flood are discussed in detail by Smith and Hart (1982); in the San Francisco Bay area, 31 people died, mostly because of landslides. At Love Creek near Ben Lomond, Santa Cruz County, 10 people were killed when a large slide and associated debris avalanche buried several houses. All together, 630 houses were destroyed or damaged and 5,500 persons were displaced. A mudslide along the northern approach to the Golden Gate Bridge closed the bridge for only the third time since it was opened in 1937. Power and telephone outages were widespread. Power was out for more than 48 hours in large areas of Santa Cruz County. The U.S. Army Corps of Engineers (1983) estimated damage to roads, houses, and commercial properties in the seven-county area at \$75 million.

The purpose of this report is to present an analysis of the meteorological settings associated with the storms and of the characteristics of the resulting flood. Data that were assembled or analyzed include rainfall rates and totals, antecedent rainfall, river stages, streamflow, and accumulated runoff of the flood and flood-crest altitudes. Magnitude and frequency of peak flows and flood volumes for selected gaging stations and durations of this flood were compared with previous large floods, especially that of December 1955. A general discussion of rainfall data sources for California and rainfall-frequency analytical techniques is given by Miller and others (1973). A description of the water-resources data obtained at gaging stations in the study area and a general definition of terms related to streamflow is presented by the U.S. Geological Survey (1976-84).

The meteorological and rainfall analyses in this report are based on data obtained by the National Oceanic and Atmospheric Administration and the State of California. Streamflow records and other streamflow data in this report were obtained as part of U.S. Geological Survey cooperative programs with the State of California and the counties of Alameda, Contra Costa, Marin, Napa, San Francisco, San Mateo, Santa Clara, Santa Cruz, and Sonoma.

GEOGRAPHICAL SETTING

The San Francisco Bay area is characterized by large, flat areas around the bay, which extend into adjacent interior valleys. The Coast Ranges form a nearly continuous barrier between the Pacific Ocean and the Central Valley (pl. 1); the only break in this barrier is where the San Joaquin and the Sacramento Rivers flow into San Francisco Bay and the Pacific Ocean through the Sacramento-San Joaquin Delta. Other than the Sacramento and the San Joaquin Rivers, streams in the study area are local, flowing with short and relatively steep courses either directly into the Pacific Ocean or into the bay.

METEOROLOGICAL SETTING

During the week of December 27, 1981, to January 2, 1982, a 500-mb ridge was located over the Aleutian Islands and western Alaska, and a low-amplitude 500-mb trough became situated over the Pacific Northwest of the United States. This trough was associated with lower-than-normal temperature. A southward movement of this westerly 500-mb trough over the West Coast brought a gradual increase in precipitation to coastal California.

The 500-mb analysis at 1600 hours P.s.t. (Pacific standard time), December 31, 1981, indicated a closed low-pressure zone over the central Pacific Ocean at 37°N/170°W (north latitude and west longitude). To the north of the low, a blocking ridge was located over western Alaska. During the early hours of January 3, the 500-mb zonal flow then split over the central Pacific Ocean. One branch flowed northward around the ridge toward Alaska, and the other branch dipped to the south of the low. Having passed the ridge or the low, the two branches reconverged over the eastern Pacific Ocean along approximately 140°W. Before reaching the coast, the flow was again dominantly westerly.

Geostationary Operational Environmental Satellite (GOES) infrared images covering western North America and the eastern Pacific Ocean for three specific times on January 3-4 are shown in figure 1. Meteorological figures used in this report are a general framework within which the meteorology of the storm is described. In the actual study of the meteorological backgrounds, much more data were used, such as hourly observations, surface maps for intermediate times, and 850-mb upper-atmosphere pressure maps.

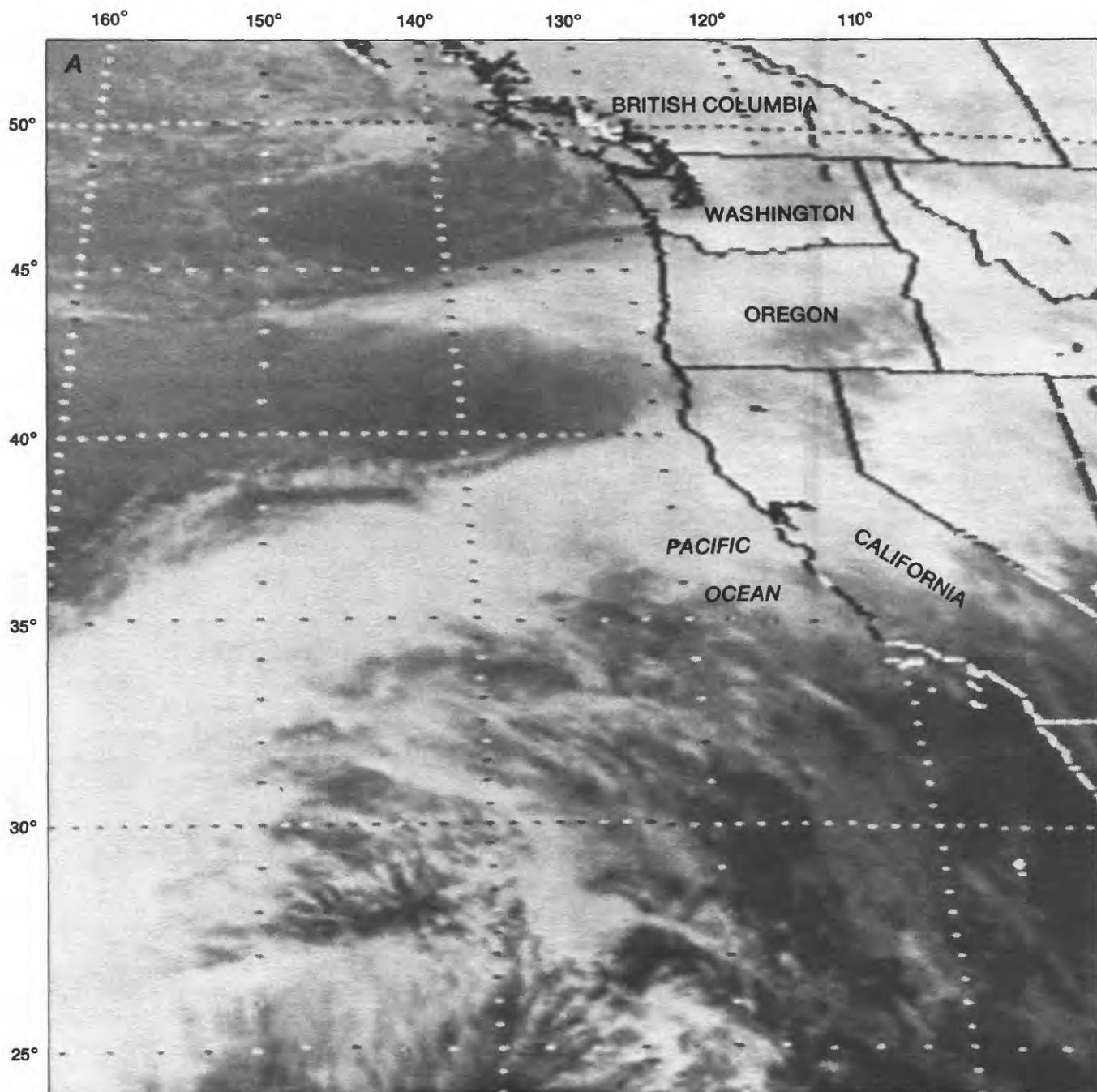


FIGURE 1.—Infrared images of Pacific Ocean and Western United States A. 1600 hours, January 3.
Light areas indicate clouds.

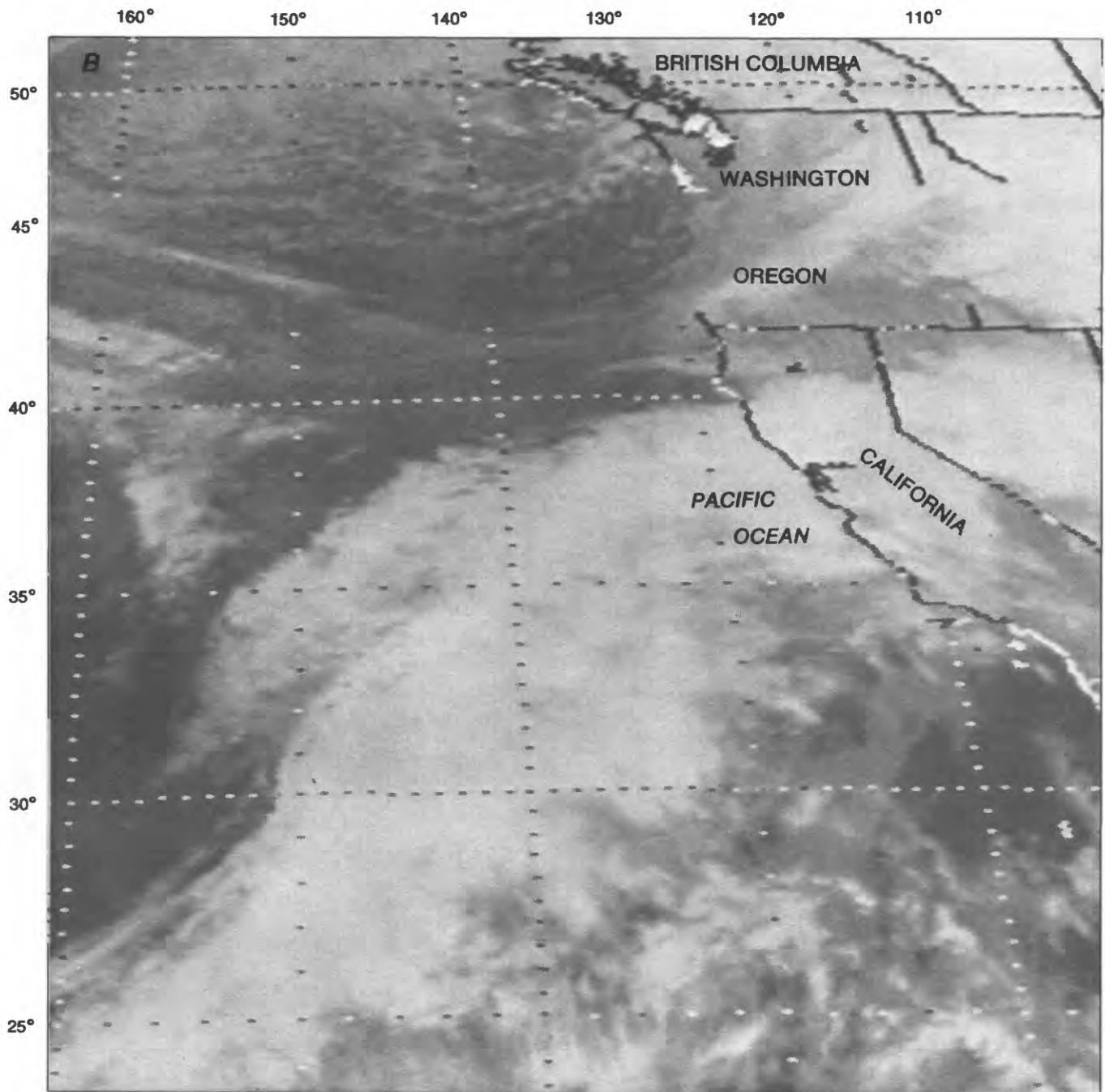


FIGURE 1.—Infrared images of Pacific Ocean and Western United States—Continued. *B.* 0400 hours, January 4.
Light areas indicate clouds.

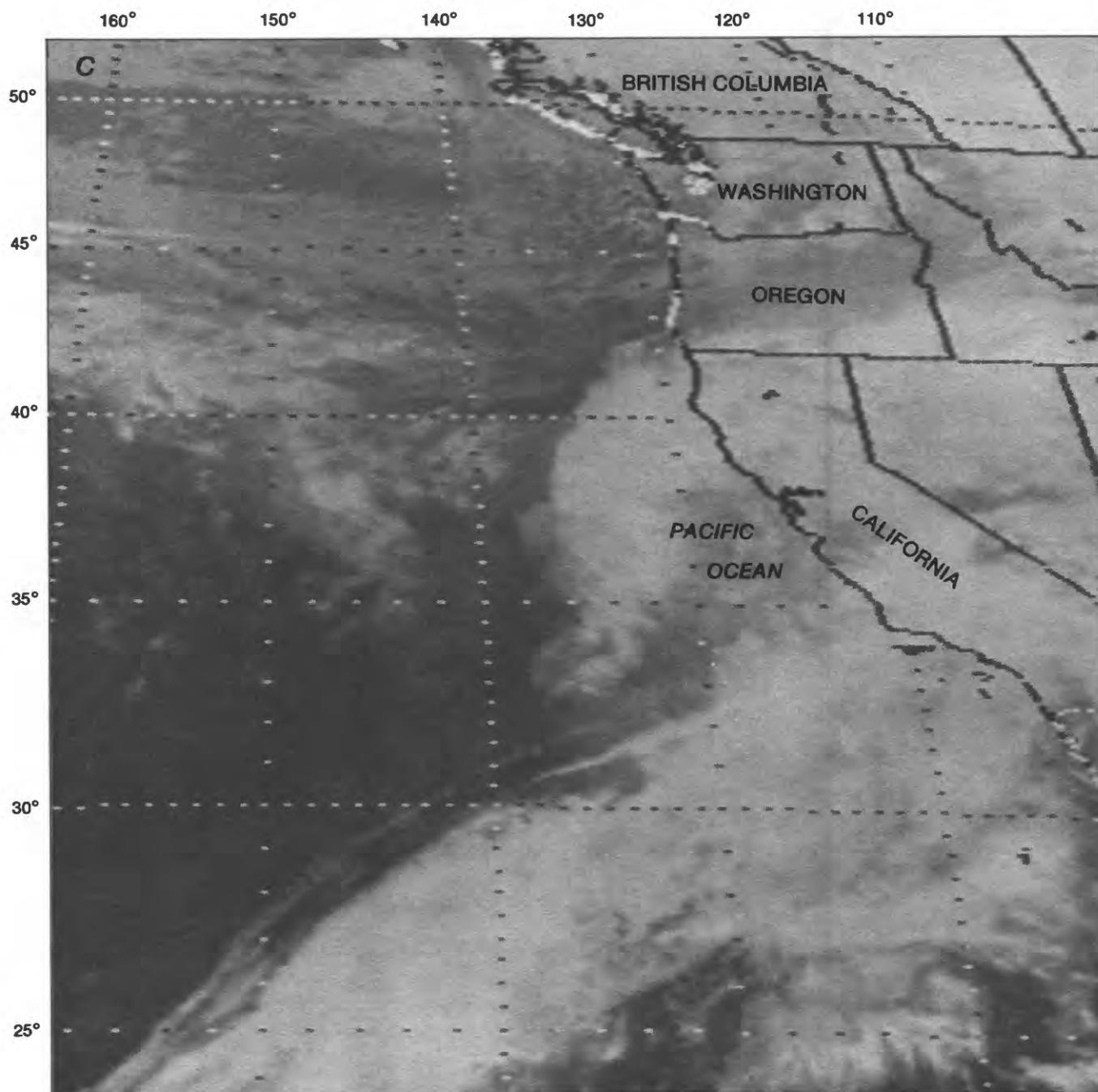


FIGURE 1.—Infrared images of Pacific Ocean and Western United States—Continued. C. 1600 hours, January 4.
Light areas indicate clouds.

On January 1, 1982, a strong upper-air short-wave trough moved across the northern Gulf of Alaska, then progressed southeastward over the eastern Pacific Ocean. The associated low-pressure zone spread rain and snow to near sea level over northern California. Upper-air flow over the West Coast became northwesterly, and cold air from Alaska and the Gulf of Alaska was advected southward. By the morning of January 2, cold, damp air had spread into northern and central California and eastern Nevada. The 700-mb dewpoint depression at Oakland, California (pl. 1), decreased from 64 to 36 °F in 12 hours ending at 0400 hours January 2, indicating that the moist condition extended through a deep layer in the lower troposphere. Freezing levels were down to sea level along the northern California coast and as low as 2,500 feet in the San Francisco Bay area (pl. 1). At San Francisco, 0700 hours January 2, the sky was overcast, and the ceiling height was 3,500 feet. Visibility was 10 miles, and relative humidity was 82 percent. After this time, the high-pressure zone located to the southwest off the California coast strengthened and started to expand onshore. As the bay area came under the influence of the high in early afternoon, the sky became almost clear and the ceiling unlimited. Visibility increased to 30 miles, and relative humidity was about 60 percent. By 2000 hours surface pressure over the bay area had risen to more than 1,022 mb. The clear-sky conditions persisted until the early morning of January 3.

Meanwhile, on the morning of January 2, a low-pressure zone began to progress southeastward. This low was associated with the downstream trough east of the upper-air blocking ridge and located at the surface off the coast of British Columbia, Canada. The low was over western Washington in the early morning of January 3, and a trough extended through western Oregon. More cold, moist air came to the Pacific Northwest. The cold airmass spread southward and reinforced the existing cold airmass in the northern half of California. By 0400 hours January 3, the jet stream also took a northwest-to-southeast direction nearly parallel to the central California coast, but just offshore. This configuration put the San Francisco Bay area just to the northeast side of the jet stream.

By 0700 hours January 3, the sky over San Francisco became overcast again, as new clouds spread into central California. After reaching Washington, the low-pressure zone changed course and moved eastward; it was over the Idaho-Montana border by about 1000 hours January 3. The low was not directly related to the main storm over the bay area. However, the new impulse of cold air into the northern half of California reinforced the cold airmass there and enabled it to hold its ground later, so that the advancing warm maritime airmass moving eastward from the Pacific Ocean stalled at the surface along the central California coast and focused the ensuing rainfall into the bay area for an extended period.

An incipient wave cyclone, which originated northeast of Hawaii, moved toward the West Coast of the United States concurrently, entraining large amounts of tropical moisture along the way. This system, which originated over the tropical ocean, had to travel northeastward over a long fetch of tropical and subtropical ocean before reaching the West Coast.

By 1600 hours January 3, the surface low-pressure zone that was part of this wave-cyclone system reached a position off the coast of northern California, and a surface warm front was situated along the central California coast. This front represented the all-important boundary between the incoming subtropical maritime airmass and the existing cold airmass over land. The warm front stalled thereafter and remained along the coast with very little eastward movement for at least 24 hours, and it acted as a quasi-stationary front. Surface pressure along the coast fell as the low approached the coast later in the evening.

This low-pressure zone moved ashore, brushing the very northern part of California, and passed over Oregon during the night of January 3-4. Turning northeastward, it moved over southwestern Montana and central Idaho by 1000 hours January 4. An occluded front extended from the low through northern California just to the north of Marin County (pl. 1), changing into a stationary front offshore. The all-important warm front was still stagnated along the central coast of California near the bay area. The dominantly southwesterly surface wind continued to bring moist maritime air into the bay area to sustain the rainfall.

The 850-mb southwesterly wind over Oakland, California, strengthened during January 3 to a speed of more than 60 knots on the early morning of January 4, partly owing to the increasing confluent flow into the bay area. This low-level jet moved slowly eastward and began funneling up the San Lorenzo River basin, resulting in a sustained increase in rainfall intensity in the Santa Cruz Mountains on the afternoon and evening of January 4.

As the low-pressure zone, centered over Oregon at 0400 hours January 4, progressed from Oregon to Idaho and Montana, a trailing incipient wave of the same system developed offshore into a closed low. This second low progressed slowly toward the central California coast and by 1300 hours January 4 centered at 36°N/127°W. Its presence maintained and reinforced the cyclonic circulation that brought the maritime air into the bay area. During the afternoon of January 4, this low approached the bay area and the quasi-stationary warm front started to creep eastward.

By 0400 hours January 5, the low-pressure zone had moved over Nevada, and the persistent warm front finally dissipated. An associated cold front extended from Nevada to the south and east of the bay area, where the northwesterly shift of low-level winds signified the end of the storm.

Lifted Index and Precipitable Water

The chronological sequences of precipitable water and lifted-index values at Oakland, California, are shown in figure 2. The precipitable water measured at Oakland Museum increased on the morning of January 3 from a minimum of 0.24 inch to a maximum of 0.91 inch on the afternoon of January 4 before decreasing.

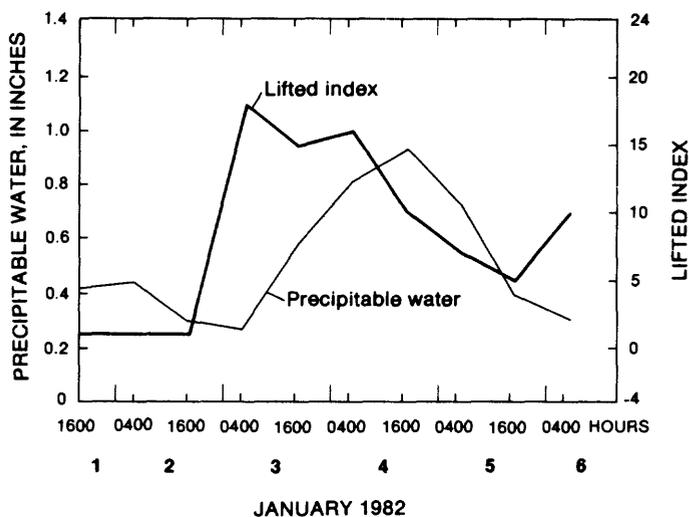


FIGURE 2.—Evolution of lifted index and precipitable water at Oakland, California, January 1982.

The increase in precipitable water and dewpoint and the rise of the freezing level all marked the arrival of the warm, moist maritime airmass from the subtropical ocean to the bay area in midmorning January 3. The lifted index had values consistently greater than +4 throughout the storm period, from the afternoon of January 3 to the morning of January 5. These values indicate a stable atmospheric structure. Specifically, the 0400 hours January 4 sounding had a lifted index of +18, indicating stability with zero probability of thunderstorm occurrence at Oakland.

Examination of time series of radar summary maps (not shown) for January 3-5 also revealed that the most frequent cloud-top heights over the San Francisco Bay area were near 13,000 feet during the storm period, with a highest cloud top of 18,000 feet observed at 1635 hours on January 4. A typical cumulonimbus deep-convective system reaches heights of 36,000 feet or more. In comparison, the cloud-top heights of the storm on January 3-5 were quite ordinary, indicating that convective processes only reached moderate heights and that deep convection was absent in this storm.

Storm rainfall was initiated by cyclone-scale events, such as frontal lifting and horizontal flow convergence, and was enhanced by local orography. The warm front stalled along the central California coast for at least 24 hours, and this focused continuous rainfall into the bay area. Persistent frontal lifting of subtropical maritime air coming from the Pacific Ocean over the existing cold airmass evidently was the primary process causing condensation and rainfall. Local orography was a primary factor in the variability of rainfall distribution in the storm.

Rainfall Distribution

The mean total rainfall, in inches, for the months of October through December 1981 for the area north of San Francisco was 29.62 inches, which is 13.20 inches greater than normal. Similarly, for the area east of San Francisco, mean total rainfall was 27.93 inches, 14.20 inches greater than normal, and for the area south of San Francisco mean total rainfall was 10.55 inches, 3.25 inches greater than normal. If rainfall in December is considered

by itself, it was 68 percent greater than normal for the northern area, 57 percent greater than normal for the eastern area, and 11 percent less than normal for the southern area. Cumulative antecedent rainfall from the beginning of the rainy season to the beginning of the storm for selected stations near San Francisco Bay is shown in table 1.

TABLE 1.--Cumulative antecedent rainfall at selected stations, October 1, 1981, to January 2, 1982

[Normal rainfall is defined as the average rainfall for October 1 to December 31 for 1941-70. Locations of stations are shown on plate 1. --, no data]

Station name	Cumulative antecedent rainfall (inch)	Normal rainfall (inch)
Ben Lomond 4	28.20	--
Berkeley	17.56	8.77
Fort Ross	30.33	15.15
Half Moon Bay	18.05	9.02
Muir Woods	25.67	14.33
Occidental	42.72	20.45
Richmond	17.10	--
San Francisco Airport	11.80	7.25
San Gregoria 2 SE	17.47	--
Santa Cruz	13.45	11.36
Wrights	25.33	16.94

Just prior to the onset of the January 1982 storm, and during the last days of December 1981, a small winter storm originated off the coast of British Columbia, Canada, and brought considerable amounts of rain to the San Francisco Bay area. For example, in the 6-day period from December 26 to 31, 3.75 inches of rain fell at Muir Woods in Marin County, and 7.70 inches fell at Boulder Creek Locatelli Ranch in Santa Cruz County. Rainfall at San Francisco Airport totaled 1.98 inches on December 29 alone. These antecedent events saturated the soil prior to the onset of the January 1982 storm.

Much of the rain fell in the lower foothills at altitudes ranging from 50 to 700 feet, rather than at or near the ridges, which reach heights of more than 2,700 feet in the Santa Cruz Mountains. When a stable airmass flows toward a mountain barrier, energy must be expended in raising the airmass, and the orography-induced vertical motion is progressively suppressed and decreases with height. The lower layer, which contains much of the moisture, then frequently flows parallel to and around the mountain without ascending further. Because the storm of January 3-5 was generally characterized by a stable atmospheric structure, this phenomenon made it possible for much of the rain to fall along the lower slopes. For instance, some of the heaviest storm rainfall occurred as strong southwesterly flow funnelled up the San Lorenzo River (pl. 1) in the Santa Cruz Mountains.

The temporal sequences of surface dewpoint at San Francisco, California, and the freezing-level height at Oakland are shown in figure 3. These two factors seem to correlate positively. The dewpoint had a low of 31 °F prior to the storm at 0100 hours on January 3. Except for a brief dip in the afternoon of January 3, the dewpoint then increased steadily to 51 °F at 1300 hours on January 4, while the corresponding height of the freezing level rose from 3,300 to about 9,000 feet.

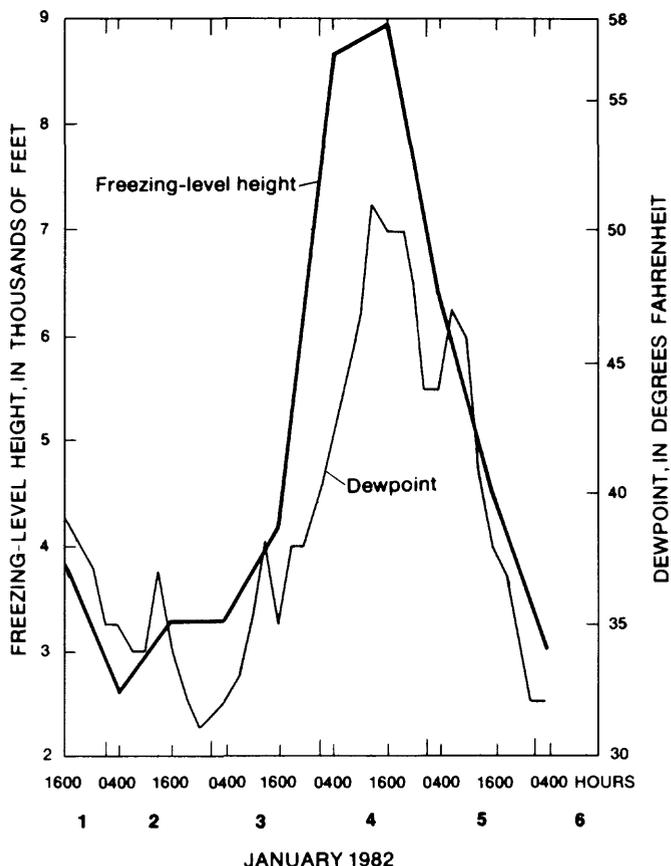


FIGURE 3.—Evolution of freezing-level height at Oakland, California, and dewpoint at San Francisco, California, January 1982.

Amounts of storm rainfall during January 3-5, 1982, and the antecedent rainfall during December 26, 1981, to January 2, 1982, for 12 stations in the bay area and vicinity are shown in figure 4. Total rainfall (December 26 to January 5) was low at San Francisco Airport, owing to the flat terrain and low altitude of its location on the west shore tideland of the bay. Total rainfall increased south of San Francisco and reached maxima of 21.80 and 22.39 inches at Boulder Creek Locatelli Ranch and Ben Lomond 4, respectively. Both stations are in the San Lorenzo River basin (pl. 1) in the Santa Cruz Mountains. In the North Bay subarea, Kentfield, located about 25 miles northwest of the San Francisco Airport, received 20.03 inches. Total rainfall to the north of San Francisco was not as great; Occidental received only 16.50 inches. Of this amount, 9.09 inches fell in the storm of January 3-5.

In addition to the rainfall data regularly published by the National Oceanic and Atmospheric Administration (1938-82), supplementary data of storm rainfall obtained through a survey after the storm was available (Goodridge, 1982). The maximum total rainfall reported was 24.75 inches at a location about 1 mile northeast of Scotts Valley (Scotts Valley 1 NNE, pl. 1) in Santa Cruz County at an altitude of 480 feet. In general, the west- or southwest-facing exposures of the Santa Cruz Mountains received the heaviest rainfall. Several other sites with similar exposures reported 20 inches or more of rainfall.

As the maritime tropical airmass, brought by the southwesterly flow to the central California coast, surged over the cold airmass on the ground, light rain began falling in the San Francisco Bay area in the afternoon of January 3.

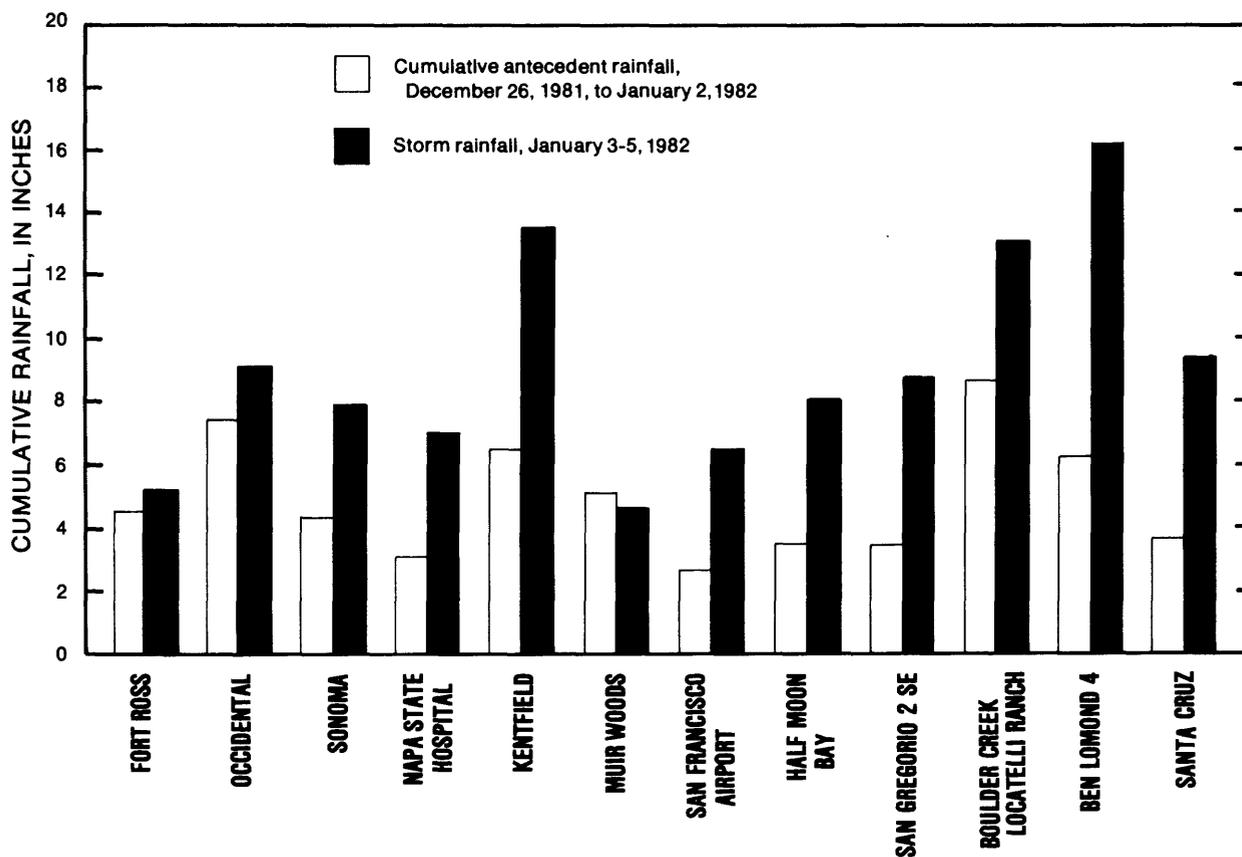


FIGURE 4.—Cumulative antecedent and storm rainfall for 12 selected stations.
(Location of stations is shown on plate 1.)

The frontal system normally would have moved eastward toward the Central Valley, but as the reinforced cold airmass held steady and the warm front stalled, persistent rain fell on the bay area from the evening of January 3 until the early morning of January 5. Rain was recorded at San Francisco Airport for 32 consecutive hours ending at 0100 hours January 5 (fig. 5A). At the recording-gage station close to the maximum rainfall center, Boulder Creek Locatelli Ranch (fig. 5B) in the Santa Cruz Mountains, light rain began shortly after 1900 hours January 3, changed to moderate rain in the early hours of January 4, and by 0500 hours became heavy. Rain continued throughout the day at an average rate of about 0.6 in/h for about 20 hours. The rain finally slackened and stopped in the morning of January 5. The storm rainfall at

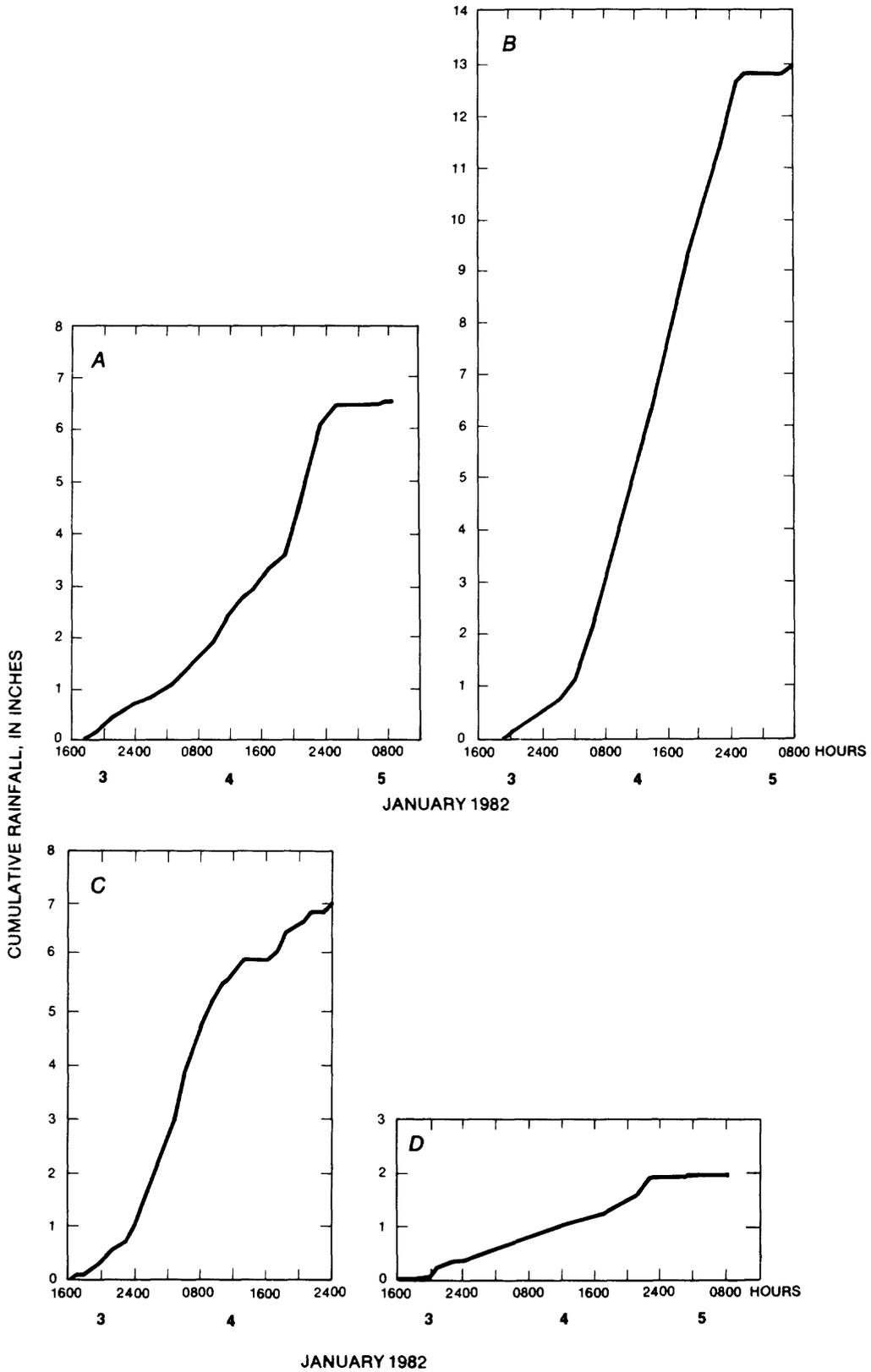


FIGURE 5.—Rainfall mass curves, January 1982. A, San Francisco Airport. B, Boulder Creek Locatelli Ranch. C, Petaluma Fire Station 3. D, San Jose.

Boulder Creek Locatelli Ranch (fig. 5B) was 13.1 inches over a 37-hour period ending 0900 hours January 5, but 11.6 inches of the total fell during a 20-hour period ending 0000 hours January 5. The storm rainfall at San Jose was only 1.97 inches (fig. 5D); by contrast, near the maximum site only 20 miles away at Boulder Creek Locatelli Ranch the total was 13.1 inches. This difference demonstrates that for this storm the Santa Clara Valley was in a rain-shadow area to the lee of the Santa Cruz Mountains.

Distribution of storm rainfall is shown in figure 6. Much of the rain fell within 25 miles east of the Pacific Coast. The storm rainfall center of 24.75 inches was located at Scotts Valley 1 NNE, and maximum rainfall occurred along a southeast to northwest axis through this center. The axis extends along the foothills bordering the San Lorenzo River basin. The area in which storm rainfall exceeded 18 inches constitutes a narrow strip near the crest of the Santa Cruz Mountains near Ben Lomond (pl. 1). The maximum rainfall from a second area of high rainfall in southern Marin County was about 16 inches (fig. 6). The center of this storm was near Kentfield (pl. 1). Large areas of southern and western Marin County had total storm rainfall exceeding 10 inches.

The time distribution of rainfall during the storm in the North Bay sub-area differs from that of the Santa Cruz Mountains subarea. At Petaluma Fire Station 3 (fig. 5C) light rain began early in the afternoon of January 3 and became heavy around midnight. Rain was heavy in the early morning of January 4 until near noon, when the intensity was greatly reduced, and the rain ended late that night. This distribution was somewhat different from that of Boulder Creek Locatelli Ranch (fig. 5B) in Santa Cruz County, where the heavy rain fell from early morning on January 4 and continued through the whole day.

CHARACTERISTICS OF MAJOR HISTORIC STORMS

Five major storms in the last 30 years have produced large amounts of rain in the San Francisco Bay area: December 1955, October 1962, December 1964, January 1967, and January 1982. One feature of all five storms was the presence of an upper-air blocking ridge over the Aleutian Islands or Alaska. Other characteristics of the storms varied considerably. Maximum 24- and 36-hour rainfall totals for the five historical storms at several meteorological stations are shown in table 2. At San Francisco Airport, the rainfall of the January 1982 storm was larger than that of the other four storms in both maximum 24- and 36-hour amounts. The 24-hour rainfall of 5.71 inches at the San Francisco Airport was the greatest at that station since records began in 1927.

123°00'

122°00'

38°00'

37°00'

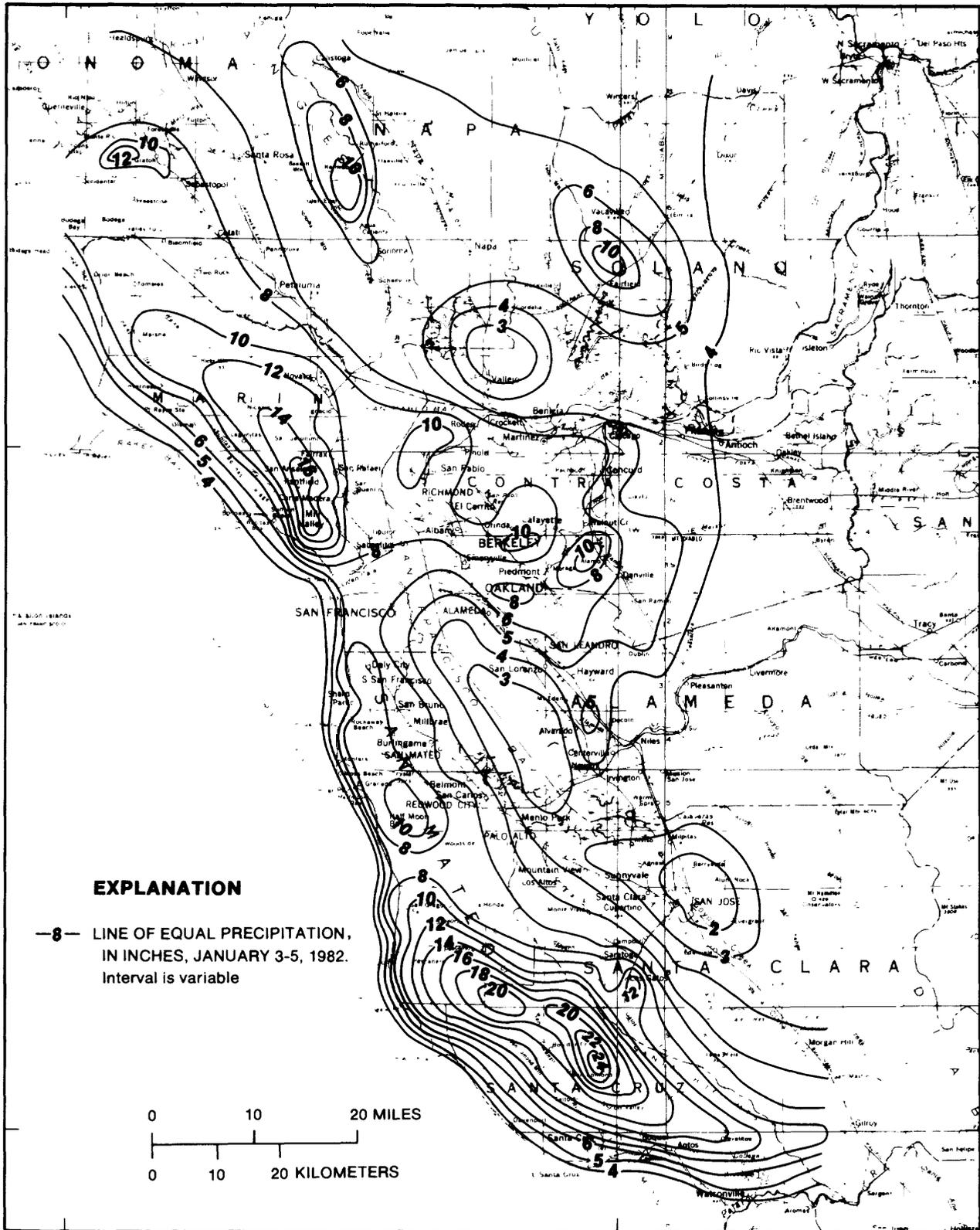


FIGURE 6.—Distribution of rainfall in the San Francisco Bay area, January 3-5, 1982.

TABLE 2.--Maximum 24- and 36-hour rainfall in five major storms for selected stations

[Locations of stations are shown on plate 1. --, no data]

Station name	Duration (hour)	Storms									
		December 1955		October 1962		December 1964		January 1967		January 1982	
		Rainfall (inch)	Ending date/hour								
Berkeley	24	3.07	22/2300	4.09	12/1900	1.72	22/0600	4.52	21/1300	6.98	5/0000
	36	3.82	23/1200	6.07	13/0700	2.43	23/0000	5.45	23/0000	7.72	5/0200
Boulder Creek Locatelli Ranch	24	12.53	22/2300	14.09	13/1900	8.25	22/1400	11.17	21/1000	12.3	5/0100
	36	15.24	23/1100	15.87	13/2200	10.05	23/0300	13.70	21/2000	13.0	5/0100
San Francisco Airport	24	2.99	23/0000	3.74	13/1700	1.17	23/0400	4.56	21/2100	5.71	5/0100
	36	3.79	23/0000	3.98	13/2200	1.47	23/0400	5.74	21/2100	6.50	5/0100
Sebastopol	24	3.73	22/1000	4.45	12/1100	2.30	23/0400	--	--	4.20	4/0500
	36	4.78	22/2200	6.66	12/2300	2.70	23/0400	--	--	4.20	4/0500

At Berkeley, the maximum 24- and 36-hour rainfall totals of the January 1982 storm were also the highest in their respective categories among the five storms. At Boulder Creek Locatelli Ranch, the January 1982 storm had the third-highest 24-hour and the fourth-highest 36-hour rainfall totals for all storms recorded at that station. Precipitable water at the time of peak rainfall intensity was less than 70 percent of the observed maximum of record. As such, climatic conditions might occur in the bay area in general, and in the central California Coast Ranges in particular, that could increase storm rainfall above those levels recorded during the January 1982 storm.

Maximum 24-hour rainfall totals for the January 1982 storm and 100-year 24-hour rainfall frequency (Miller and others, 1973) for selected stations are given in table 3. At Petaluma Fire Station 3 and San Francisco Airport, the 24-hour rainfall totals exceeded the magnitudes of the 100-year flood.

An estimate of the maximum 24-hour rainfall total at Scotts Valley 1 NNE (pl. 1), the rainfall center of the January 1982 storm, can be made by using the mass curve for Boulder Creek Locatelli Ranch (fig. 5B) as a guide. If the intensity pattern for Scotts Valley 1 NNE was similar, the maximum 24-hour rainfall would be about 23 inches, which exceeds the 100-year 24-hour rainfall of 13 inches (Miller and others, 1973).

TABLE 3.--Maximum 24-hour storm rainfall
with estimated 100-year 24-hour rainfall

[Locations of stations are shown on plate 1. Estimates of 100-year 24-hour rainfall are from rainfall-frequency analyses by Miller and others (1973)]

Station name	Station location (latitude/longitude)	Storm 24-hour rainfall (inch)	100-year 24-hour rainfall (inch)
Berkeley	37°52'N/122°15'W	6.98	9.0
Boulder Creek Locatelli Ranch	37°09'N/122°12'W	12.3	18.0
Petaluma Fire Station 3	38°14'N/122°38'W	6.4	5.2
San Francisco Airport	37°37'N/122°23'W	5.71	4.5
Walnut Creek 2 ENE	36°54'N/122°01'W	4.38	5.0

SOURCES OF FLOOD DATA

Streamflow data for the January 3-5, 1982, flood were obtained at 79 gaging stations and 3 miscellaneous sites (pl. 1). The period of record, basin size, and comparative flood data for these stations (table 4) are taken from the U.S. Geological Survey (1937-70; 1971-74; and 1976-84). Only 23 stations in the San Francisco Bay area have streamflow records of 25 years or longer. The selected sites provide a reasonable sample of the different hydrologic conditions of the San Francisco Bay area. Most of the gaging stations represented in table 4 are located on streams that are generally unaffected by regulation or diversion upstream from the station.

The crest-stage gages are devices that record peak stages from which peak flow can be estimated. These gages were operated on a systematic basis between 1958 and 1972. A summary of peak-flow data obtained at crest-stage gages located throughout California is presented by Waananen (1973). The January 1982 peak flows were determined by indirect measurements at several inactive gaging stations.

TABLE 4.--Maximum flood stages and discharges at selected

[Station locations and subareas are shown on plate 1. Period
cubic foot per second per

Station or site No.	Station name	Drainage area (mi ²)	Period of record
Santa Cruz Mountains subarea			
11159150	Corralitos Creek near Corralitos	10.6	1957-72
11159200	Corralitos Creek at Freedom	27.8	1956-82
11159400	Green Valley Creek near Corralitos	7.05	1960-73, 1982
11159690	Aptos Creek near Aptos	10.2	¹ 1959-82
11159770	Laurel Creek near Laurel	.93	1960-73
11159800	West Branch Soquel Creek near Soquel	12.2	1958-72
11159940	Soquel Creek near Soquel	32.0	1968-72
11160000	Soquel Creek at Soquel	40.2	1951-82
11160020	San Lorenzo River near Boulder Creek	6.17	1968-82
Site 1 ²	San Lorenzo River tributary at Boulder Creek	.115	--
11160060	Bear Creek at Boulder Creek	16.0	1977-82
11160070	Boulder Creek at Boulder Creek	11.3	1976-82
11160300	Zayante Creek at Zayante	11.1	1957-82
11160500	San Lorenzo River at Big Trees	106	1936-82
11161500	Branciforte Creek at Santa Cruz	17.3	1940-43, 1952-68
11161590	Laguna Creek near Davenport	3.07	1969-76
11161800	San Vicente Creek near Davenport	6.07	1969-82
11161900	Scott Creek above Little Creek, near Davenport	25.1	1936-37, 1958-73, 1982
11162470	Pescadero Creek tributary near La Honda	.22	1961-73
11162500	Pescadero Creek near Pescadero	45.9	1951-82
11162540	Butano Creek near Pescadero	18.3	1959-74
11162570	San Gregorio Creek at San Gregorio	50.9	1969-82
11162600	Purisima Creek near Half Moon Bay	4.83	1958-69
11162630	Pilarcitos Creek at Half Moon Bay	27.2	1966-82

See footnotes at end of table.

gaging stations in the San Francisco Bay area

of record is in calendar years. --, no data. (ft³/s)/mi², square mile; mi², square mile. >, greater than]

Maximum previously known			January 1982 flood				
Calendar year	Gage height (foot)	Discharge (ft ³ /s)	Date of flood	Gage height (foot)	Discharge (ft ³ /s)	Unit peak runoff [(ft ³ /s)/mi ²]	Recurrence interval (year)
Santa Cruz Mountains subarea--Continued							
1958	7.55	1,970	--	10.37	2,120	200	9
1955	15.6	3,620	4	16.66	5,610	202	40
1963	56.62	925	--	57.65	1,200	170	15
1963	10.82	2,110	4	12.10	3,980	390	40
1963	32.31	290	--	31.92	270	290	6
1967	11.47	4,530	--	12.5	3,750	307	9
1969	9.03	2,700	--	16.37	6,000	188	9
1955	22.33	15,800	4	21.85	9,700	241	14
1973	9.10	672	4	11.48	1,050	170	11
--	--	--	--	--	72	626	(³)
1980	10.36	2,080	4	13.30	4,480	280	7
1978	8.03	1,630	4	9.50	3,500	310	14
1978	8.52	4,620	4	8.86	3,670	331	7
1955	22.55	30,400	5	28.85	29,700	280	33
1955	22.04	8,100	4	20.95	6,650	384	29
1974	3.68	283	--	5.04	650	212	38
1974	5.83	937	4	8.90	2,280	376	>100
1939-41	12.96	7,550	--	10.08	4,220	168	20
1973	51.75	51	--	51.21	42	191	23
1955	21.27	9,420	4	20.92	9,400	205	21
1962	10.04	1,600	--	22.46	2,100	115	11
1973	17.5	3,730	4	21.28	7,910	155	43
1967	5.42	343	--	6.80	1,100	228	>100
1968	11.20	1,290	4	13.08	4,750	175	>100

TABLE 4.--Maximum flood stages and discharges at selected

Station or site No.	Station name	Drainage area (mi ²)	Period of record
West Bay subarea			
11152900	Cedar Creek near Bell Station	12.8	1961-82
11153470	Llagas Creek above Chesbro Reservoir, near Morgan Hill	9.63	1971-82
11153800	Alec Canyon near Morgan Hill	.91	1960-73
11153900	Uvas Creek above Uvas Reservoir, near Morgan Hill	21.0	1961-82
11154100	Bodfish Creek near Gilroy	7.40	1959-82
11154200	Uvas Creek near Gilroy	71.2	1959-82
11158900	Pescadero Creek near Chittenden	10.2	1970-82
11159000	Pajaro River at Chittenden	1,186	1939-82
11162720	Colma Creek at South San Francisco	10.8	1963-82
11162800	Redwood Creek at Redwood City	1.82	1959-82
11163500	Los Trancos Creek at Stanford	7.46	1930-41, 1982
11164500	San Francisquito Creek at Stanford University	37.4	1930-41, 1950-82
11166000	Matadero Creek at Palo Alto	7.26	1952-82
11169000	Guadalupe River at San Jose	146	1929-82
11169500	Saratoga Creek at Saratoga	9.22	1933-82
11169580	Calabazos Creek tributary at Mt. Eden Road, near Saratoga	.37	1972-78, 1982
11169600	Prospect Creek at Saratoga Golf Course, near Saratoga	.27	1972-78, 1982
11169800	Coyote Creek near Gilroy	109	1960-82
11172100	Upper Penitencia Creek at San Jose	21.5	1961-82
East Bay subarea			
11176000	Arroyo Mocho near Livermore	38.2	1912-30, 1955, 1963-82
11176180	Arroyo las Positas at El Charro Road, near Pleasanton	75.0	1977-82

See footnotes at end of table.

gaging stations in the San Francisco Bay area--Continued

Maximum previously known			January 1982 flood				
Calendar year	Gage height (foot)	Discharge (ft ³ /s)	Date of flood	Gage height (foot)	Discharge (ft ³ /s)	Unit peak runoff [(ft ³ /s)/mi ²]	Recurrence interval (year)
West Bay subarea--Continued							
1963	6.85	3,490	4	4.74	1,150	89.8	4
1978	7.50	969	4	6.86	980	102	4
1963	--	367	--	58.95	158	174	4
1962	13.18	6,580	4	11.99	5,200	248	5
1963	8.25	1,240	4	8.86	1,180	159	10
1963	17.66	9,490	5	20.21	8,370	118	14
1980	7.11	667	--	8.15	846	82.9	6
1955	32.46	24,000	5	25.21	12,100	⁴ 10.2	(³)
1973	11.80	2,880	4	11.63	2,550	236	40
1963	9.36	644	4	6.95	379	208	5
1940	4.07	647	--	4.30	930	125	21
1955	13.6	5,560	4	12.42	5,220	140	(³)
1973	5.57	1,380	4	3.66	⁵ 628	86.5	4
1958	16.55	9,150	4	--	⁵ 2,370	⁴ 16.2	(³)
1955	6.40	2,730	4	7.06	1,720	187	13
1978	5.50	120	--	4.90	110	297	4
1975	4.93	52	--	4.98	55	204	5
1963	12.6	10,100	4	12.93	6,840	62.8	4
1958	--	2,100	5	5.06	⁵ 469	21.8	2
East Bay subarea--Continued							
1955	--	1,880	5	7.55	1,140	29.8	11
1980	7.28	1,350	5	7.64	⁵ 1,230	16.4	4

TABLE 4.--Maximum flood stages and discharges at selected

Station or site No.	Station name	Drainage area (mi ²)	Period of record
East Bay subarea--Continued			
11176200	Arroyo Mocho near Pleasanton	142	1962-82
11176300	Tassajara Creek near Pleasanton	26.8	1914-19, 1921-30, 1978-82
11176400	Arroyo Valle above Lang Canyon, near Livermore	130	1963-82
11176500	Arroyo Valle near Livermore	147	1912-30, 1957-82
11177000	Arroyo de la Laguna near Pleasanton	405	1912-30, 1969-82
11179000	Alameda Creek near Niles	633	1891-1982
11180500	Dry Creek at Union City	9.39	1916-19, 1959-82
11180825	San Lorenzo Creek above Don Castro Reservoir, near Castro Valley	18.0	1980-82
11180960	Cull Creek above Cull Creek Reservoir, near Castro Valley	5.79	1978-82
11181000	San Lorenzo Creek at Hayward	37.5	1939-40, 1946-82
11181008	Castro Valley Creek at Hayward	5.51	1971-82
11181390	Wildcat Creek at Vale Road, at Richmond	7.79	⁷ 1965-75, 1975-82
11182030	Rheem Creek at San Pablo	1.49	1960-82
11182100	Pinole Creek at Pinole	10.0	1938-77, 1982
11182400	Arroyo del Hambre at Martinez	15.1	1964-82
11182500	San Ramon Creek at San Ramon	5.89	1952-82
11183000	San Ramon Creek at Walnut Creek	47.9	1952-82
11183600	Walnut Creek at Concord	85.2	1968-82
11183700	Little Pine Creek near Alamo	1.22	1974-82

See footnotes at end of table.

gaging stations in the San Francisco Bay area--Continued

Maximum previously known			January 1982 flood				
Calendar year	Gage height (foot)	Discharge (ft ³ /s)	Date of flood	Gage height (foot)	Discharge (ft ³ /s)	Unit peak runoff [(ft ³ /s)/mi ²]	Recurrence interval (year)
East Bay subarea--Continued							
1980	11.87	2,220	5	13.97	4,330	30.5	>100
1980	8.50	750	5	11.70	2,280	85.1	>100
1980	5.40	5,710	5	6.22	7,030	54.1	9
1955	13.93	18,200	6	--	⁵ 1,060	17.2	(³)
1914	--	9,810	5	19.61	11,400	28.1	(³)
1955	14.9	29,000	5	12.96	12,700	20.1	(³)
1962	5.27	930	4	3.88	⁵ 579	61.7	5
--	--	--	4	8.70	1,150	63.9	(³)
1980	4.28	638	5	8.71	1,690	292	8
1958	⁶ 20.82	5,100	5	20.15	7,740	206	21
1979	7.20	670		7.36	1,010	183	(³)
1980	9.53	1,280	4	15.80	2,050	263	>100
1969	6.95	477	4	6.63	364	244	5
1958	11.63	1,660	4	--	2,250	225	20
1973	10.93	1,960	4	12.65	2,200	146	7
1962	16.98	1,600	4	11.79	1,220	207	10
1963	14.40	7,980	5	15.55	7,400	154	10
1973	14.0	8,000	5	19.10	13,300	156	10
1978	2.18	86	4	2.41	138	113	9

TABLE 4.--Maximum flood stages and discharges at selected

Station or site No.	Station name	Drainage area (mi ²)	Period of record
North Bay subarea			
11455900	Napa River at Calistoga	21.9	1975-82
11456000	Napa River near St. Helena	81.4	1929-32, 1939-82
11458000	Napa River near Napa	218	1929-32, 1959-82
11458100	Milliken Creek near Napa	17.3	1970-82
11458300	Napa Creek at Napa	14.9	1970-82
11458350	Tulucay Creek at Napa	12.6	1971-82
11458500	Sonoma Creek at Agua Caliente	58.4	1955-81, 1982
11459500	Novato Creek at Novato	17.6	1946-82,
11460000	Corte Madera Creek at Ross	18.1	1951-82
11460100	Arroyo Corte Madera del Presidio at Mill Valley	4.69	1965-73, 1975-82
11460440	Nicasio Creek near Nicasio	1.74	1962-73, 1982
11460600	Lagunitas Creek near Point Reyes Station	81.7	1974-82
Site 2 ²	Verde Canyon, tributary to Walker Creek near Marshall	3.1	--
11460800	Walker Creek near Tomales	40.1	1959-82
Site 3 ²	Unnamed tributary to Americano Creek	1.09	--
11460900	Roscoe Creek at Bodega Bay	.25	1961-73, 1982
11460920	Salmon Creek near Bodega Bay	15.7	1962-75
11467000	Russian River near Guerneville	1,338	1939-82

¹From 1959-70, record from site downstream, drainage area 12.2 mi².

²Miscellaneous site.

³Not computed.

⁴Flow regulated.

⁵Not peak for water year.

⁶Peak gage height during December 22, 1955 flood; discharge 4,790 ft³/s.

⁷Station relocated to new site in 1975.

⁸Revised in 1987.

gaging stations in the San Francisco Bay area--Continued

Maximum previously known			January 1982 flood				
Calendar year	Gage height (foot)	Discharge (ft ³ /s)	Date of flood	Gage height (foot)	Discharge (ft ³ /s)	Unit peak runoff [(ft ³ /s)/mi ²]	Recurrence interval (year)
North Bay subarea--Continued							
1978	17.21	4,400	4	12.68	⁵ 2,580	118	3
1955	18.17	12,600	4	14.41	⁵ 7,670	94.2	3
1963	27.59	⁸ 19,200	4	25.65	20,900	95.9	(³)
1980	9.36	3,160	4	8.7	⁵ 2,930	169	(³)
1978	11.16	2,660	4	12.76	3,190	214	5
1980	5.96	2,020		7.38	2,360	187	6
1955	17.10	8,880	4	16.5	8,300	142	4
1980	11.94	2,360	4	14.46	5,000	284	>100
1955	17.45	3,620	4	19.81	7,200	398	>100
1970	7.52	1,180	4	8.11	1,170	249	13
1967	15.38	560		--	610	351	8
1980	18.72	4,430	4	26.96	22,100	271	(³)
--	--	--	4	--	1,770	571	(³)
1966	22.23	5,420	4	31.37	18,800	469	(³)
--	--	--	4	--	1,010	927	(³)
1970	9.71	76	--	--	210	840	>100
1973	19.61	2,260	--	--	7,400	471	>100
1964	49.6	93,400	4	37.16	⁵ 58,900	44	(³)

ANTECEDENT CONDITIONS

All local streams were subject to flooding by the January 1982 storm. Flooding from stream runoff, however, was not a major problem. Greater than normal antecedent rainfall, together with the prolonged heavy rain, liquified the supersaturated soil cover and caused numerous slope failures, debris avalanches, and debris flows on many steep, unstable slopes. Debris flows also aggravated flooding by damming streams in the immediate area and by sending large trees and other debris downstream to produce more temporary dams. Most damage resulted from combinations of slope failure and partial damming of the stream channel by debris. In the northern part of the bay area, high tides coincided with maximum rainfall runoff, causing backwater on streams and flooding of low-lying populated areas. For simplicity in describing flood characteristics, the San Francisco Bay area was divided into four subareas, the Santa Cruz Mountains, West Bay, East Bay, and North Bay (pl. 1).

Nilsen and others (1976) analyzed bay-area landslides in recent years and found that they generally occur during heavy winter storms when cumulative antecedent rainfall exceeds 10 to 15 inches. The initial rainfall accumulation in the early part of the wet season is most important in providing favorable subsurface conditions for landsliding. Antecedent wet-season rainfall at all sample stations exceeded the threshold prerequisite, sometimes by a large margin (table 1).

With the nearly continuous passage of storms through the region during these months and with soils generally saturated by December, the potential for flooding during the subsequent winter months of January and February was significantly increased.

Streamflow responded to the greater-than-normal rainfall during November and December 1981 with a rapid increase in accumulated runoff (figs. 7-10). Departures from average flows for the months October to January were based on the 5-year average, 1977-81 (table 5). Departures for average monthly flow for the months October-January of the 1956 water year are also shown in figures 7-10 indicate differences in antecedent conditions prior to the December 1955 and January 1982 floods.

TABLE 5.--Average percentage of annual flow for October through January 1977-81 at selected gaging stations in the San Francisco Bay area

[Station locations are shown on plate 1]

Station No.	Station name	Percentage of annual flow			
		October	November	December	January
11160000	Soquel Creek near Soquel	1.8	3.2	7.3	26.1
11169500	Saratoga Creek at Saratoga	1.8	2.6	5.5	24.4
11183000	San Ramon Creek at Walnut Creek	2.4	3.4	6.9	30.3
11459500	Novato Creek at Novato	.9	3.5	11.8	37.1

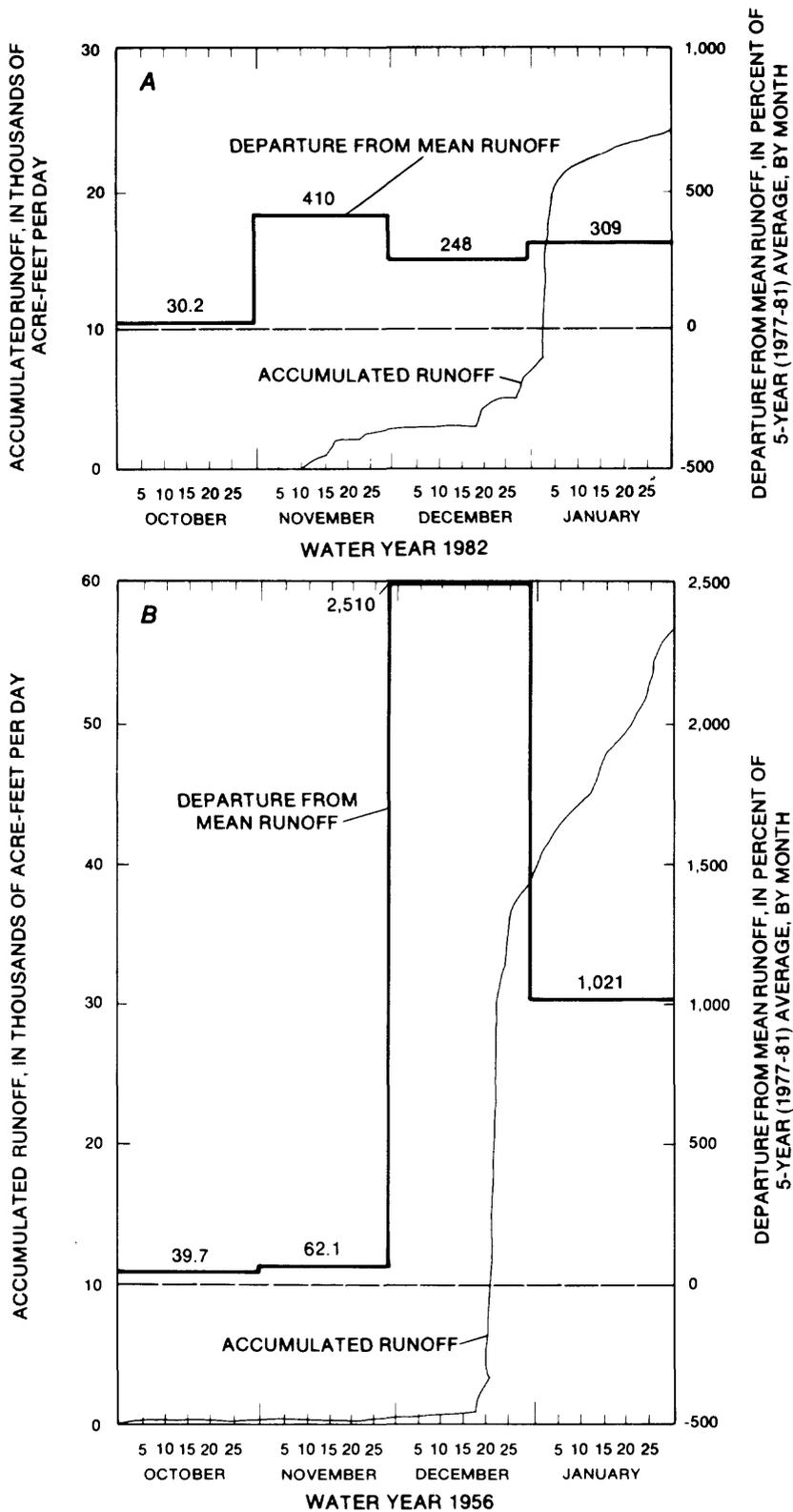


FIGURE 7.—Accumulated runoff between October 1 and January 31 for water years 1956 and 1982 for Soquel Creek at Soquel (11160000). A, water year 1982. B, water year 1956.

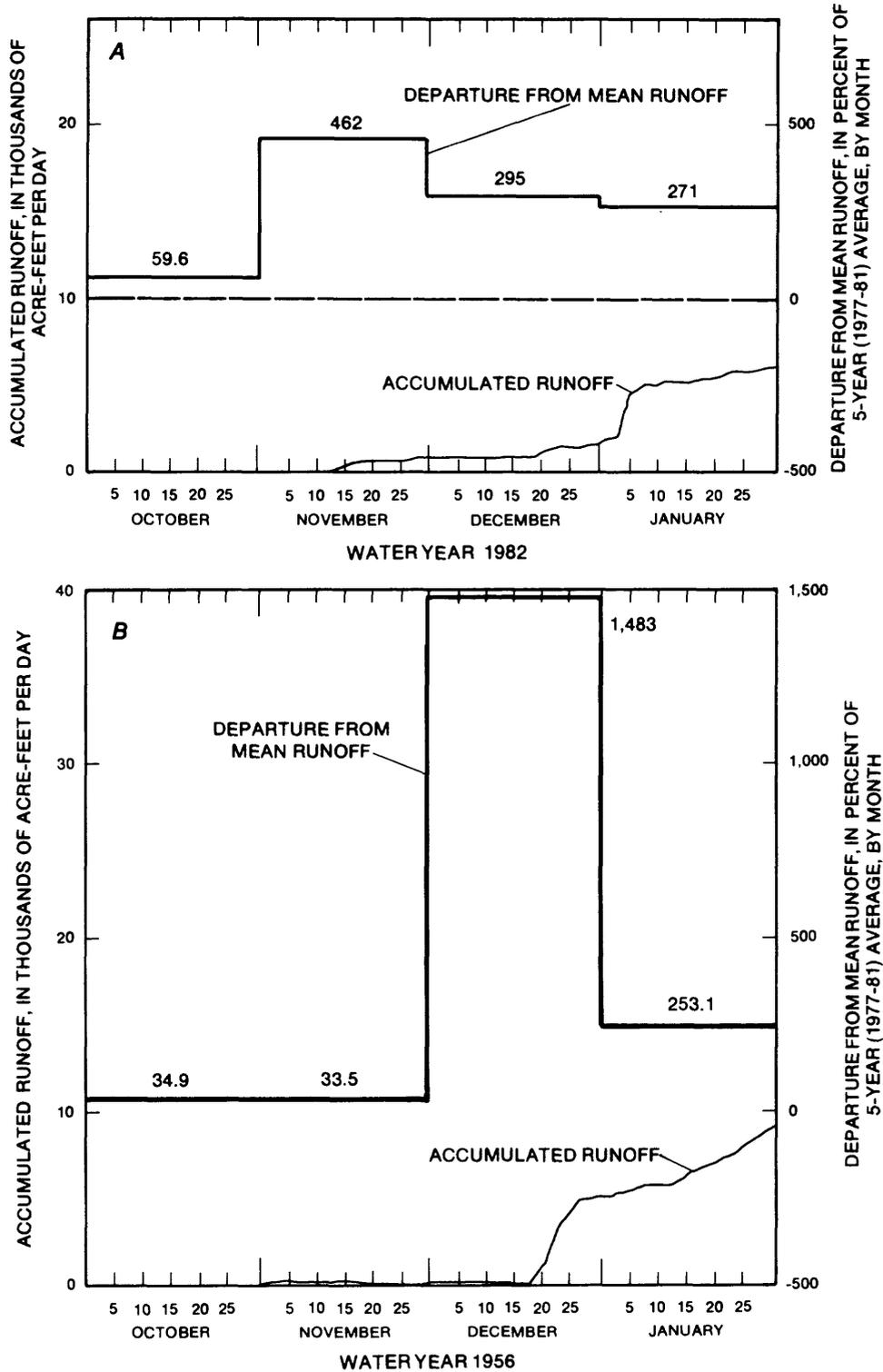


FIGURE 8.—Accumulated runoff between October 1 and January 31 for water years 1956 and 1982 for Saratoga Creek at Saratoga (11169500). A, water year 1982. B, water year 1956.

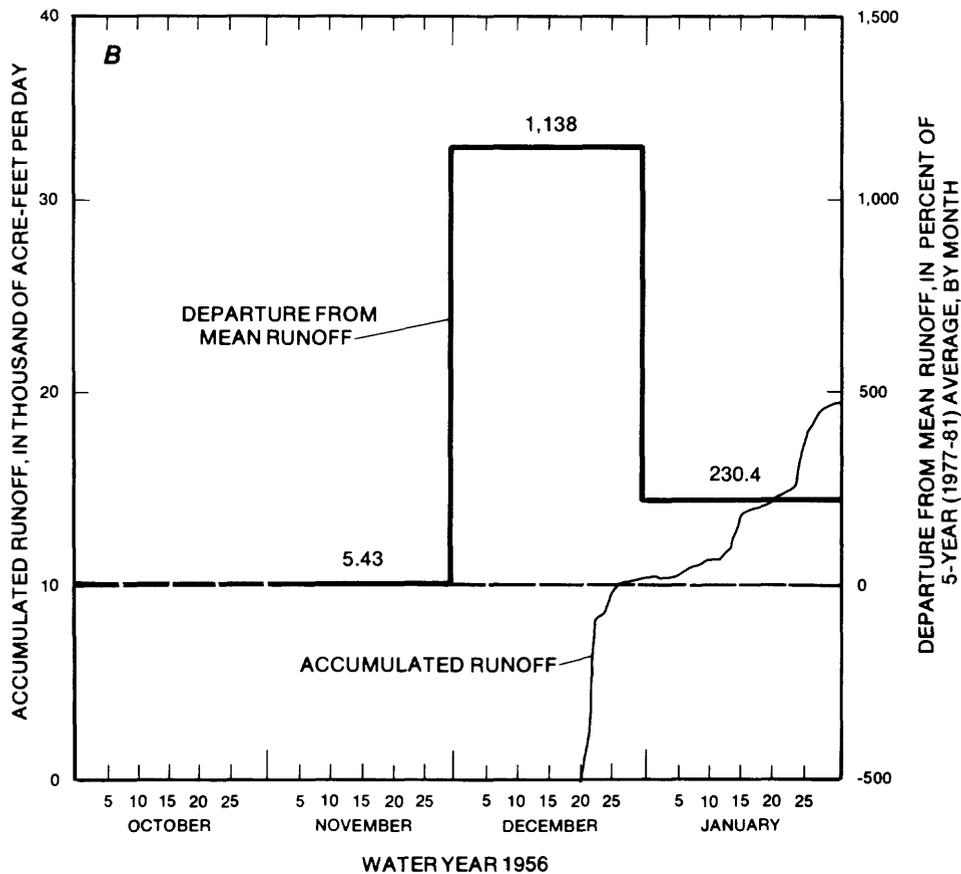
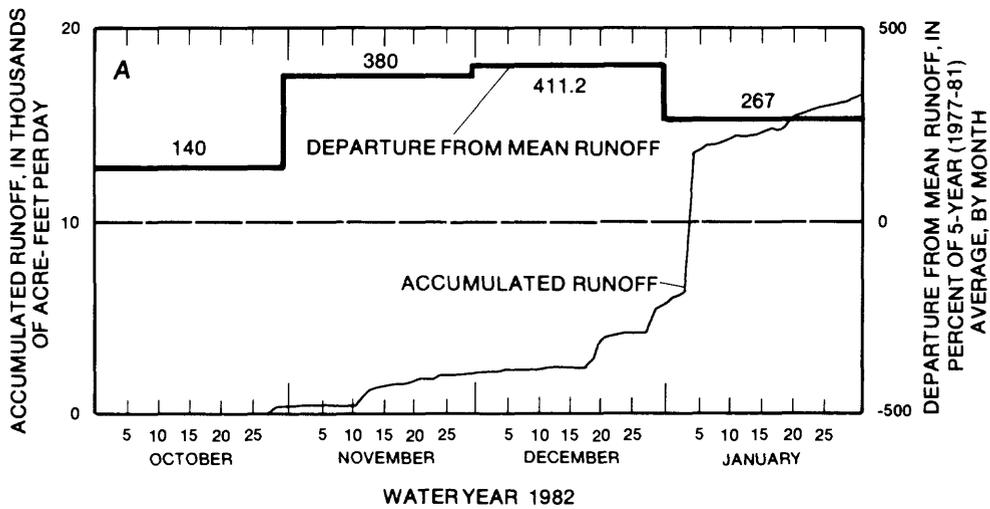


FIGURE 9.—Accumulated runoff between October 1 and January 31 for water years 1956 and 1982 for San Ramon Creek at Walnut Creek (11183000). *A*, water year 1982. *B*, water year 1956.

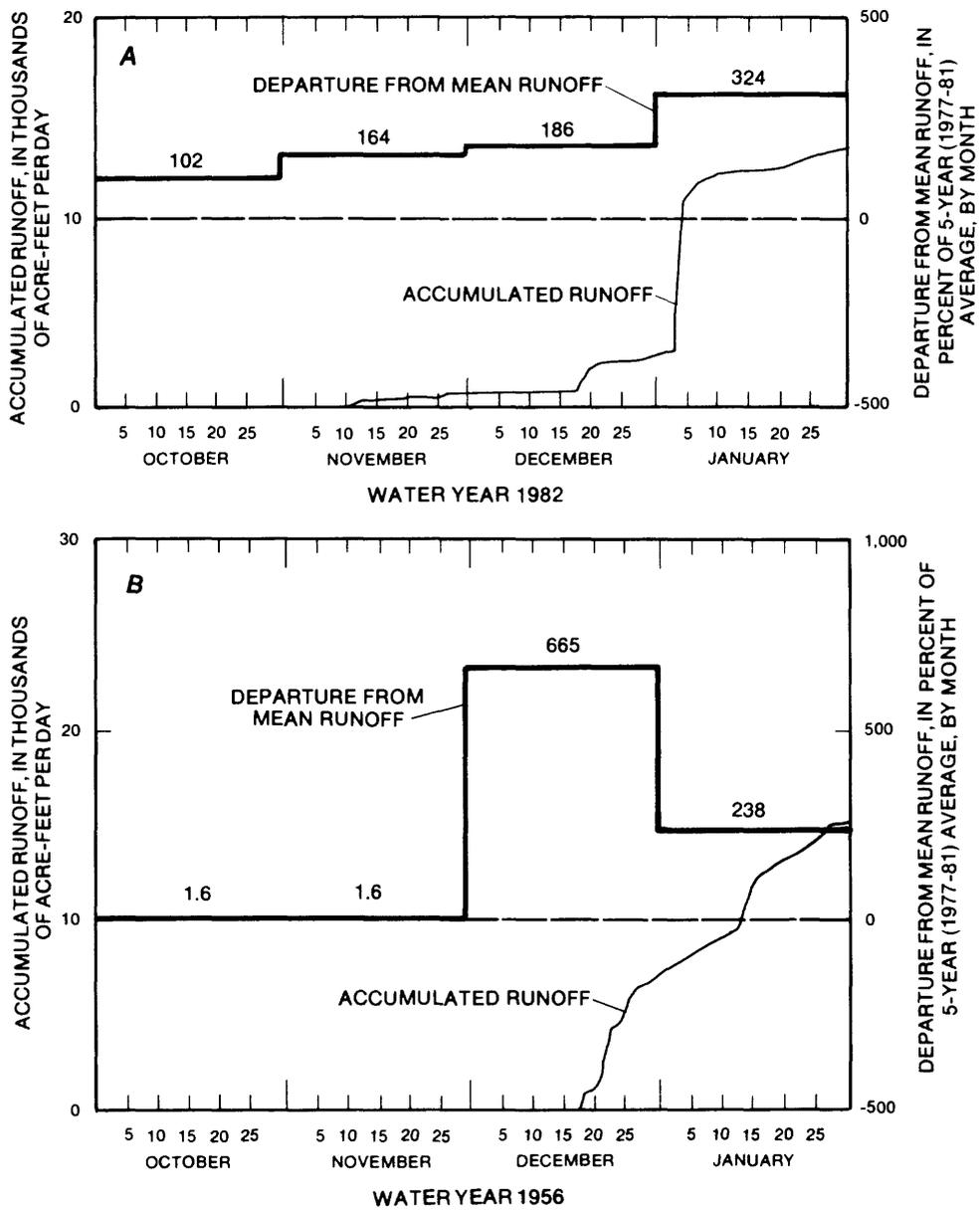


FIGURE 10.—Accumulated runoff between October 1 and January 31 for water years 1956 and 1982 for Novato Creek at Novato (11459500). *A*, water year 1982. *B*, water year 1956.

Monthly runoff at the four selected gaging stations in the bay area was more than 100 percent of normal by the end of November (figs. 7-10). Subsequent storms in December were of sufficient intensity and frequency that streamflows continued to exceed 100 percent of the 1977-81 base by the end of December. Following the storm of January 3-5, 1982, flows did not return to normal until after February. Most of the increase in streamflow followed major storms on November 11-16, December 15-29, and January 3-5.

A study of the January 1982 flood in the Santa Cruz Mountains (Blodgett and Poeschel, 1988) found that major floods on the San Lorenzo River generally result from greater-than-normal antecedent rainfall for a period up to 60 days prior to the peak, combined with subsequent intense frontal-type storms. The impact of a series of storms during the months November and December on streams in the San Francisco Bay area is indicated by the accumulated runoff plots (figs. 7-10) at gaging stations on four selected streams in the San Francisco Bay area. The runoff for these stations for about 60 days (November and December) prior to the 1982 peak averaged 320 percent of the 1977-81 average runoff. In comparison, the average runoff for 60 days (November and December) prior to the December 1955 flood averaged about 740 percent of the 5-year average for these stations. Runoff during November 1955 was deficient, however, averaging 26 percent of the 5-year average, whereas in December 1955 runoff was about 1,450 percent of average (figs. 7-10). Antecedent rainfall during the December 1955 flood was a factor for less than 30 days prior to the flood rather than 60 days.

FREQUENCY OF ANNUAL PEAK FLOWS

On many streams in the San Francisco Bay area, peak flows during the January 1982 flood were among the largest since the flood of December 1955. Peaks on some streams located on the west or east side of San Francisco Bay (pl. 1) for the January 1982 flood were less than record peaks, however, and for others the January flood was not the annual peak for the 1982 water year. To determine the relative magnitude of the January 1982 flood, data for 66 gaging stations in the study area (pl. 1) were used to develop flood-frequency relations for sites that are not significantly regulated during floods and that have systematic records of at least 10 years' duration (table 4). The recurrence interval of annual peak flows is the average number of years between exceedences of a flood of a given magnitude. In the analysis of annual peaks, a log-Pearson type III distribution was used to define the frequency curves from which recurrence intervals for peak flows were obtained.

In order to estimate frequency relations of peak flows for streams in the study area, a generalized skew of -0.70 was derived using procedures described by the U.S. Water Resources Council (1981). The standard error of the generalized skew was 0.27 log units, similar to that given by the U.S. Water Resources Council (1981). A generalized skew of peak flow of -0.78, as determined by Blodgett and Poeschel (1988), was applicable to streams in the Santa Cruz Mountains subarea. An evaluation of four streams in the North Bay subarea that have 27 or more years of record suggests that the skew in this subarea should be larger than the skew in the Santa Cruz Mountains and West Bay subareas, a trend similar to that shown on the map of generalized skew coefficients given

by the U.S. Water Resources Council (1981). Several of these streams, however, are affected by regulation, which tends to make the apparent skew more negative. The generalized skew of -0.7 was weighted on the basis of individual gaging-station skew when calculating the frequency of the 1982 flood for streams in the San Francisco Bay area.

Recurrence intervals given in table 4 for some gaging stations in the Santa Cruz Mountains subarea are different from those determined by Blodgett and Poeschel (1988). These differences result from revision of the peak discharges, use of a different historical period for which the 1982 peak is the maximum, and variations in graphical interpretation of the frequency estimates determined in accordance with procedures of the U.S. Water Resources Council (1981). The median recurrence interval of the January 1982 peak for the 66 stations is 10 years. Peak discharge of streams in the Santa Cruz Mountains and North Bay subareas (pl. 1) had the largest recurrence intervals. Several streams in the East and West Bay subareas had higher peaks during the flood of March 31, 1982, than during the January 1982 flood.

REGIONAL CHARACTERISTICS OF FLOOD

Areal Variation in Unit Peak Runoff

Unit peak runoff, the ratio of peak discharge to size of the contributing drainage basin, can indicate variations in the intensity and amount of rain, as well as the effect of the basin size on subsequent flood runoff. Unit peak runoff at gaging stations on unregulated streams (table 4) for the flood ranged from 16.4 (ft³/s)/mi² for Arroyo las Positas at El Charro Road, near Pleasanton (drainage area 75.0 mi²), to 927 (ft³/s)/mi² for an unnamed tributary to Americano Creek (drainage area 1.09 mi²). Unit peak runoffs (table 6) from the January 1982 storm were greater in the North Bay subarea than in other areas around San Francisco Bay. The subarea with the next highest unit peak runoffs,

the Santa Cruz Mountains, received the greatest amount of storm rainfall for 24 hours (table 2). Median unit peak runoff is 250 (ft³/s)/mi² in the North Bay subarea and 220 (ft³/s)/mi² in the Santa Cruz Mountains. Median values in the West and East Bay subareas are 159 to 129 (ft³/s)/mi².

TABLE 6.--*Areal variation in unit peak runoff for unregulated streams during the January 1982 flood*

[Locations of study subareas are shown on plate 1. (ft³/s)/mi², cubic feet per second per square mile]

Subarea	Number of basins	Unit peak runoff [(ft ³ /s)/mi ²]		
		Median	Minimum	Maximum
Santa Cruz Mountains ...	24	220	115	626
West Bay	17	159	21.8	297
East Bay	20	129	16.4	292
North Bay	18	250	44.0	927
All sites	79	187	16.4	927

Areal Differences in Flood Frequency

Many gaging stations in the San Francisco Bay area are on streams that are not regulated or

are subject to minor diversion and some regulation during the low-flow season. Data for the January 1982 flood peaks and recurrence intervals at selected gaging stations in the study area (table 7) were used to define the areal differences in recurrence interval throughout the study area.

The subareas used for defining the areal distribution of unit peak runoff also were used to define the areal distribution in the frequency of the January 1982 flood. The median recurrence interval for each of the subareas shown on plate 1 is given in table 7. In general, streams with flows of higher recurrence intervals are located in the Santa Cruz Mountains and East Bay subareas (table 7). The range in median recurrence interval varied from 20 years in the Santa Cruz Mountains to 5 years in the West Bay. The peak discharges at 10 stations had recurrence intervals of more than 100 years (table 4).

TABLE 7.--Areal differences in recurrence interval of the January 1982 flood

[Locations of study subareas are shown on plate 1. >, greater than]

Subarea	Number of gaging stations	Recurrence interval (year)		
		Median	Minimum	Maximum
Santa Cruz Mountains ...	23	20	6	>100
West Bay	16	5	2	40
East Bay	16	10	4	>100
North Bay	11	8	3	>100
All stations ..	66	10	2	>100

COMPARISON WITH HISTORIC FLOODS

Although peak discharges were not exceptionally high in most basins, the January 1982 flood in the San Francisco Bay area is considered one of the most damaging events in the area in the past half century. In a study of the January 1982 flood in the Santa Cruz Mountains, the magnitude of flood peaks and runoff volumes related not only to the amount of storm rainfall but also to the amount of antecedent rainfall during a period 60 days prior to a major flood (Blodgett and Poeschel, 1988). As a means of evaluating the relative magnitude and areal distribution of the January 1982 flood, antecedent conditions for historic floods on selected streams in the San Francisco Bay area were compared.

Peak Flow

A comparison of the January 1982 flood peak with historic data for unregulated streams in the San Francisco Bay area indicates that this flood ranks with the largest that have occurred throughout the region. Since 1940, previous significant floods in the bay area occurred in February 1940, December 1955, January 1963, and January 1978. Flood data for most of the gaging stations in the San Francisco Bay area that were in operation during both the 1955 and 1982 floods are given in table 8. These data indicate that the December 1955 peak was larger than the 1982 peak at 10 of the 16 sites. For the 16 gaging stations where peak data were obtained for both December 1955 and January 1982, the median recurrence intervals are 11 years for the December 1955 peak and 17 years for the January 1982 peak. However, the recurrence interval of

TABLE 8.--Comparison of discharge and recurrence interval for various durations

[For 1982, the median recurrence interval of the peak flow is 17 years and for the flow is 11 years and of the 1-day discharge is 13 years. Locations of study

Station No.	Station name	Date	Peak	
			Discharge (ft ³ /s)	Recurrence interval (year)
Santa Cruz Mountains subarea				
11159200	Corralitos Creek at Freedom	12-22-55	3,620	12
		1- 4-82	5,610	40
11160000	Soquel Creek at Soquel ¹	12-23-55	15,800	62
		1- 4-82	9,700	14
11160500	San Lorenzo River at Big Trees ¹	12-23-55	30,400	36
		1- 5-82	29,700	33
11161500	Branciforte Creek at Santa Cruz	12-22-55	8,100	77
		1- 4-82	6,650	29
11162500	Pescadero Creek near Pescadero ¹	12-23-55	9,420	21
		1- 4-82	9,400	21
West Bay subarea				
11166000	Matadero Creek near Palo Alto ¹	12-22-55	854	7
		1- 4-82	628	4
11169500	Saratoga Creek at Saratoga ¹	12-22-55	2,730	46
		1- 4-82	1,720	13
East Bay subarea				
11176000	Arroyo Mocho near Livermore	12-23-55	1,880	33
		1- 5-82	1,140	11
11181000	San Lorenzo Creek at Hayward	12-22-55	4,790	8
		1- 5-82	7,740	21
11182100	Pinole Creek at Pinole	12-22-55	697	4
		1- 4-82	2,250	20
11182500	San Ramon Creek at San Ramon	12-22-55	1,350	12
		1- 4-82	1,220	10
11183000	San Ramon Creek at Walnut Creek	12-23-55	6,890	9
		1- 5-82	7,400	10

See footnotes at end of table.

at selected gaging stations for December 1955 and January 1982 floods

1-day discharge is 18 years. For 1955, the median recurrence interval of the peak subareas and stations are shown on plate 1. ft³/s, cubic foot per second]

1-day discharge		3-day discharge		8-day discharge	
Volume (acre-foot)	Recurrence interval (year)	Volume (acre-foot)	Recurrence interval (year)	Volume (acre-foot)	Recurrence interval (year)
Santa Cruz Mountains subarea--Continued					
--	--	--	--	--	--
4,540	30	7,960	19	8,820	10
17,500	>100	28,300	>100	35,200	>100
8,530	18	12,100	11	14,200	6
33,700	62	51,400	30	69,700	30
29,200	36	47,100	24	53,900	11
--	--	--	--	--	--
--	--	--	--	--	--
11,000	41	17,300	31	25,400	25
6,940	14	10,000	7	12,100	6
West Bay subarea--Continued					
664	15	1,080	16	1,440	11
649	13	828	8	1,040	8
1,190	14	2,680	22	4,590	20
1,410	25	2,640	11	3,160	9
East Bay subarea--Continued					
--	--	--	--	--	--
1,210	17	1,690	22	1,980	6
4,960	22	8,430	24	10,700	14
4,600	18	8,930	29	10,100	11
572	5	1,340	7	1,970	7
--	--	--	--	--	--
649	10	1,170	13	1,480	8
603	9	1,050	10	1,390	7
5,300	13	8,310	12	9,980	9
4,220	9	7,400	9	9,260	8

TABLE 8.--Comparison of discharge and recurrence interval for various durations

Station No.	Station name	Date	Peak	
			Discharge (ft ³ /s)	Recurrence interval (year)
North Bay subarea				
11456000	Napa River at St. Helena	12-22-55	12,6000	8
		1- 4-82	² 7,670	3
11458500	Sonoma Creek at Aqua Caliente (Boyles Hot Springs)	12-22-55	8,800	5
		1- 4-82	8,300	4
11459500	Novato Creek at Novato ³	12-22-55	1,120	3
		1- 4-82	5,000	>100
11460000	Corte Madera Creek at Ross ³	12-22-55	3,620	6
		1- 4-82	7,200	>100

¹Flows revised from those published by Blodgett and Poeschel (1984).

²Not annual peak.

³Flow affected by regulation.

the January peak was equal to or less than the December 1955 flood at 10 of the 16 sites. Bar charts of annual peak discharges for the period of record for six of the stations included in table 8 are shown in figure 11. These stations were selected because (1) data for both the 1955 and 1982 floods are available and (2) the streams are representative of basins in the San Francisco Bay area. The January 1982 flood is the largest of record at only one of the six streams included in figure 11, Corte Madera Creek at Ross. The December 1955 flood is maximum of record at four of the six sites, and at Corte Madera Creek at Ross it is the second highest of record. These data indicate that the amount and rate of rainfall during the December 1955 storm were more severe than those contributing to the January 1982 flood.

Flow Volume and Associated Frequency

Volumes of runoff for durations of 1, 3, and 8 consecutive days were used to define the magnitude of the January 1982 flood. Streamflow hydrographs for typical gaging stations in the study area (fig. 12) indicate that most of the

at selected gaging stations for December 1955 and January 1982 floods--Continued

1-day discharge		3-day discharge		8-day discharge	
Volume (acre-foot)	Recurrence interval (year)	Volume (acre-foot)	Recurrence interval (year)	Volume (acre-foot)	Recurrence interval (year)
North Bay subarea--Continued					
16,800	10	32,700	16	59,200	15
9,620	4	15,900	3	23,600	3
9,940	5	20,200	6	36,300	9
--	--	--	--	--	--
1,290	5	3,060	6	5,670	6
5,650	>100	8,670	>100	9,330	15
4,680	11	8,740	14	14,800	19
7,620	78	10,000	22	13,300	13

floodflow is included within an 8-day period, as noted by Blodgett and Poeschel (1988), for streams in the Santa Cruz Mountains subarea.

For determining flood-volume frequency relations, runoff volumes for each duration were defined by selecting consecutive daily flows that give the greatest magnitude of flow for the selected duration. The maximum 1-day flow always occurred within the period of maximum 3- and 8-day flows; however, the maximum 3-day volume did not always occur within the 8-day period. The 8-day volume of flow was on the average 24 percent greater than the 3-day volume for the stations shown in figure 12.

The peak flows, volumes for 1, 3, and 8 days, and corresponding recurrence intervals of the December 1955 and January 1982 floods for selected gaging stations in the San Francisco Bay area are given in table 8. Generalized skew coefficients were derived using log-Pearson type III analytical procedures (U.S. Water Resources Council, 1981) for flow volumes of 1-, 3-, and 8-day durations for those stations in table 8 with 25 or more years of record. The coefficients are -0.7 for 1-day, -0.7 for 3-day, and -0.8 for 8-day durations. The recurrence intervals of flow volumes for the various durations were computed using log Pearson type III distribution with generalized skew coefficients, which were weighted on the basis of station skew.

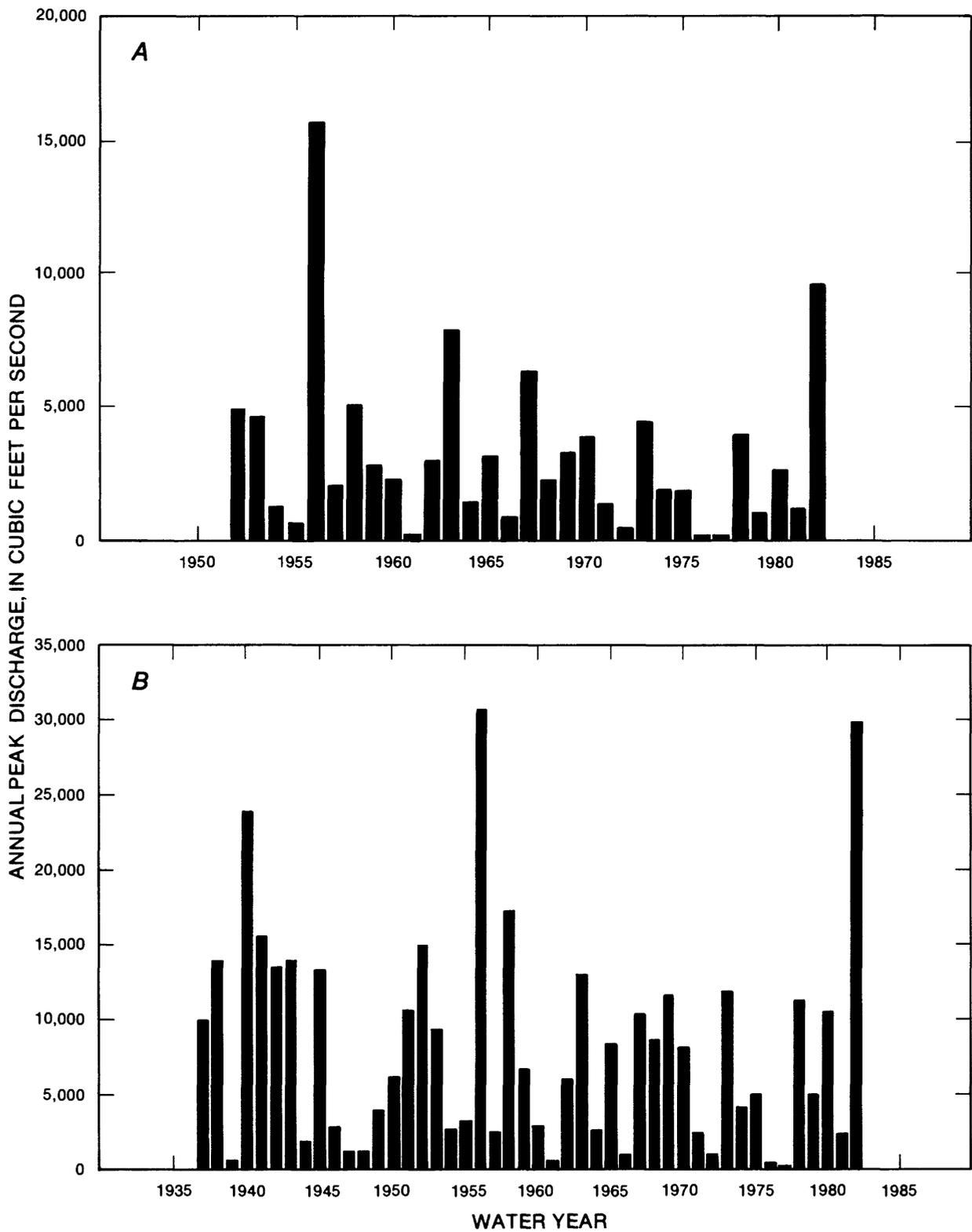


FIGURE 11.—Annual peak discharge at selected gaging stations in the San Francisco Bay area. A, Soquel Creek at Soquel (11160000). B, San Lorenzo River at Big Trees (11160500).

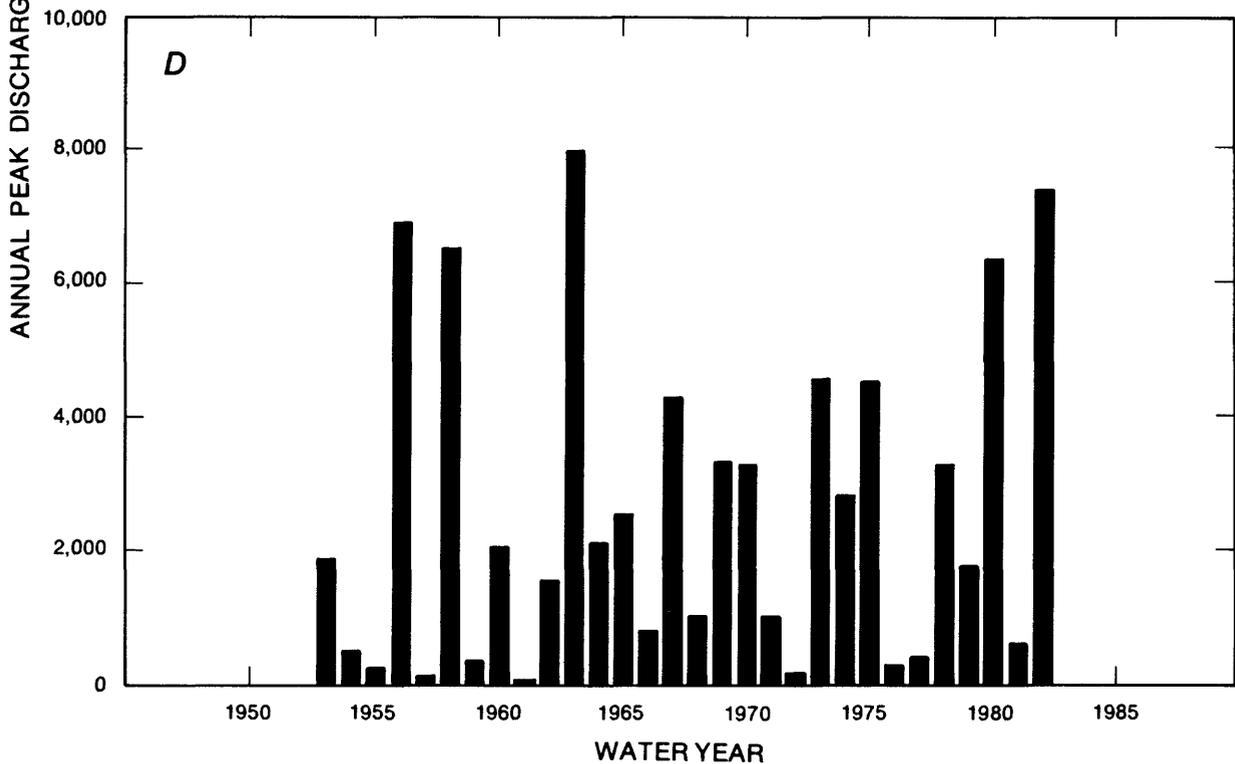
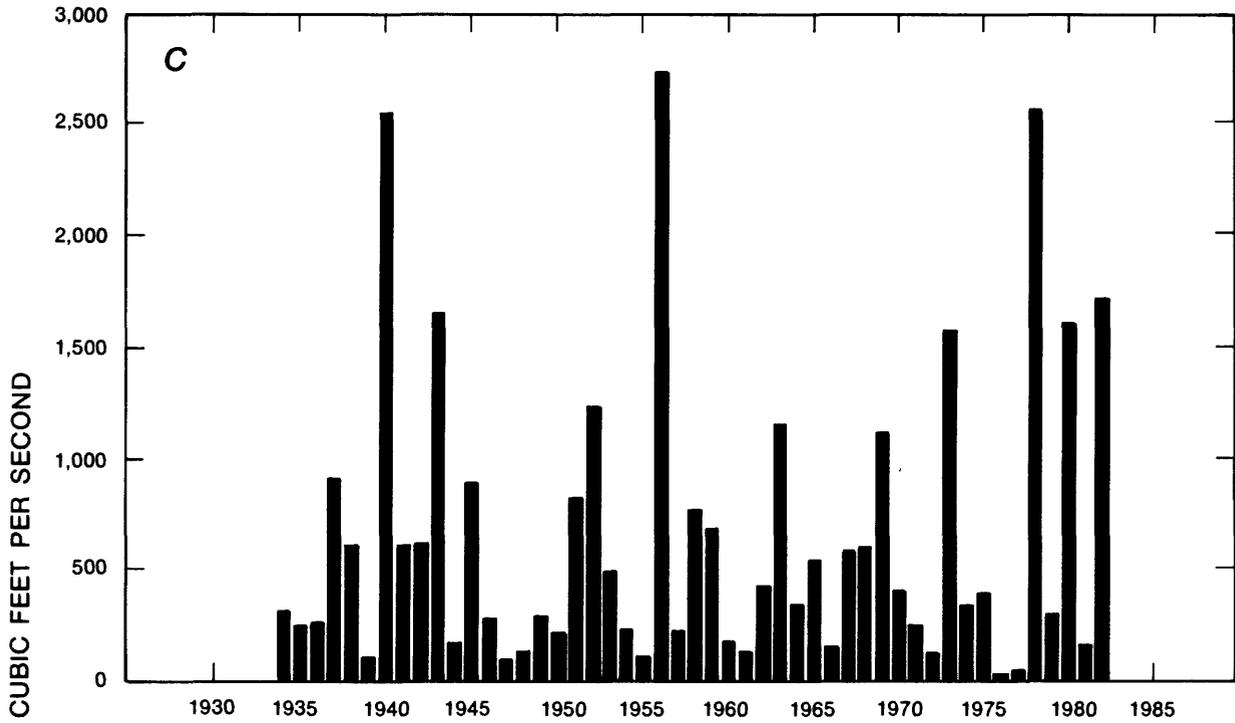


FIGURE 11.—Annual peak discharge at selected gaging stations in the San Francisco Bay area—Continued. C, Saratoga Creek at Saratoga (11169500). D, San Ramon Creek at Walnut Creek (11183000).

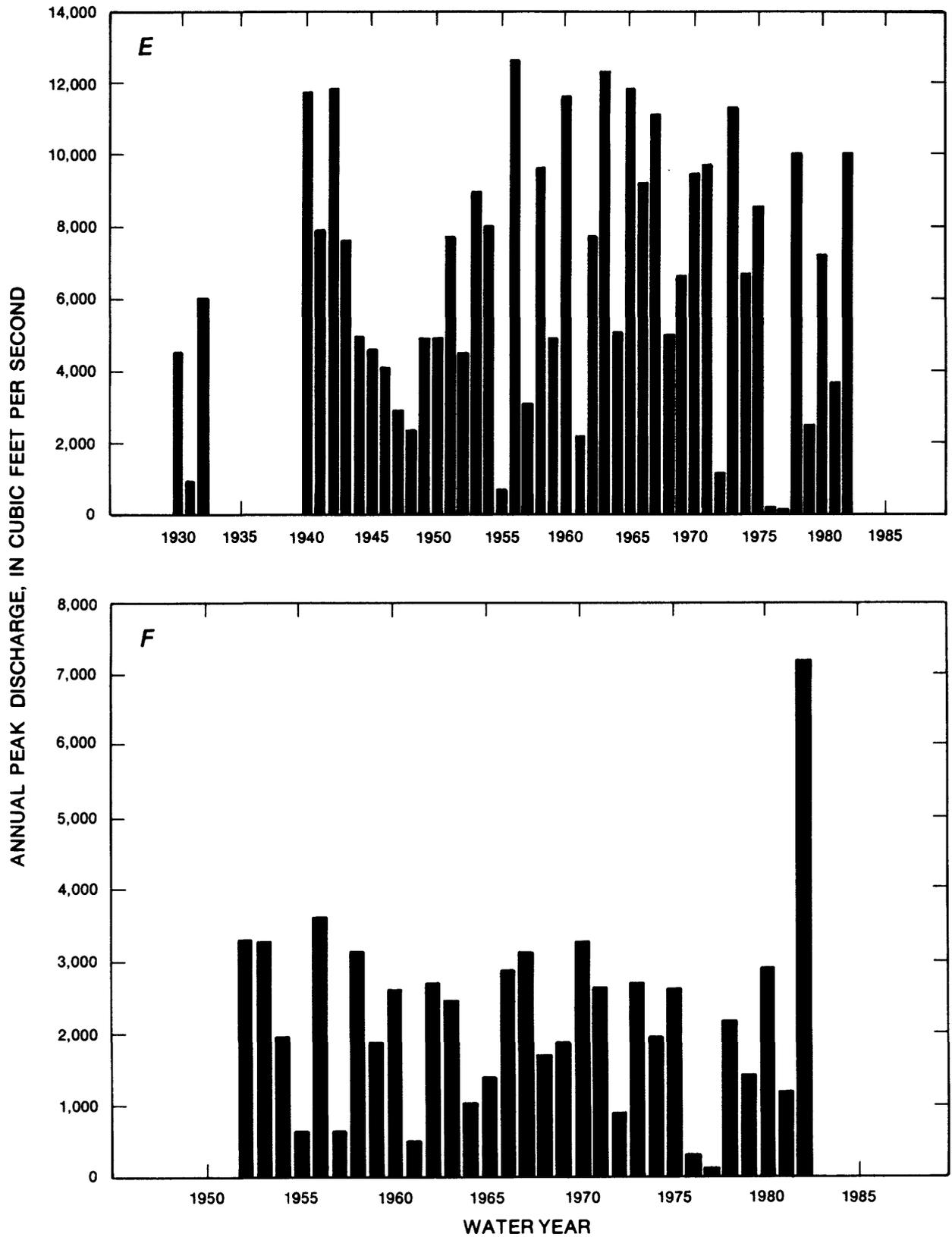


FIGURE 11.—Annual peak discharge at selected gaging stations in the San Francisco Bay area—Continued.
E, Napa River near St. Helena (11456000). *F*, Corte Madera Creek at Ross (11460000).

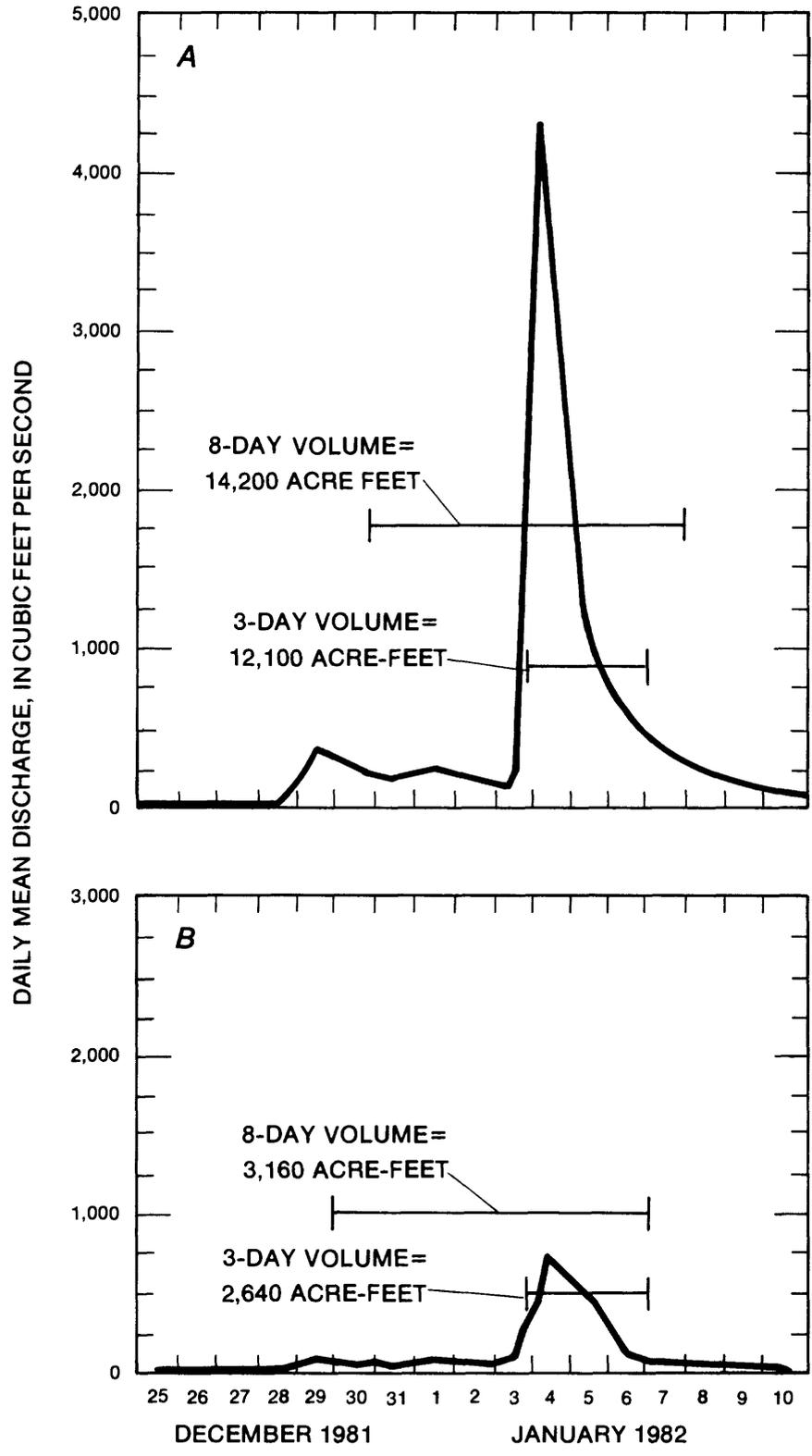


FIGURE 12.—Discharge at selected gaging stations in the San Francisco Bay area for the period December 25, 1981, to January 10, 1982. *A*, Soquel Creek at Soquel (11160000). *B*, Saratoga Creek at Saratoga (11169500).

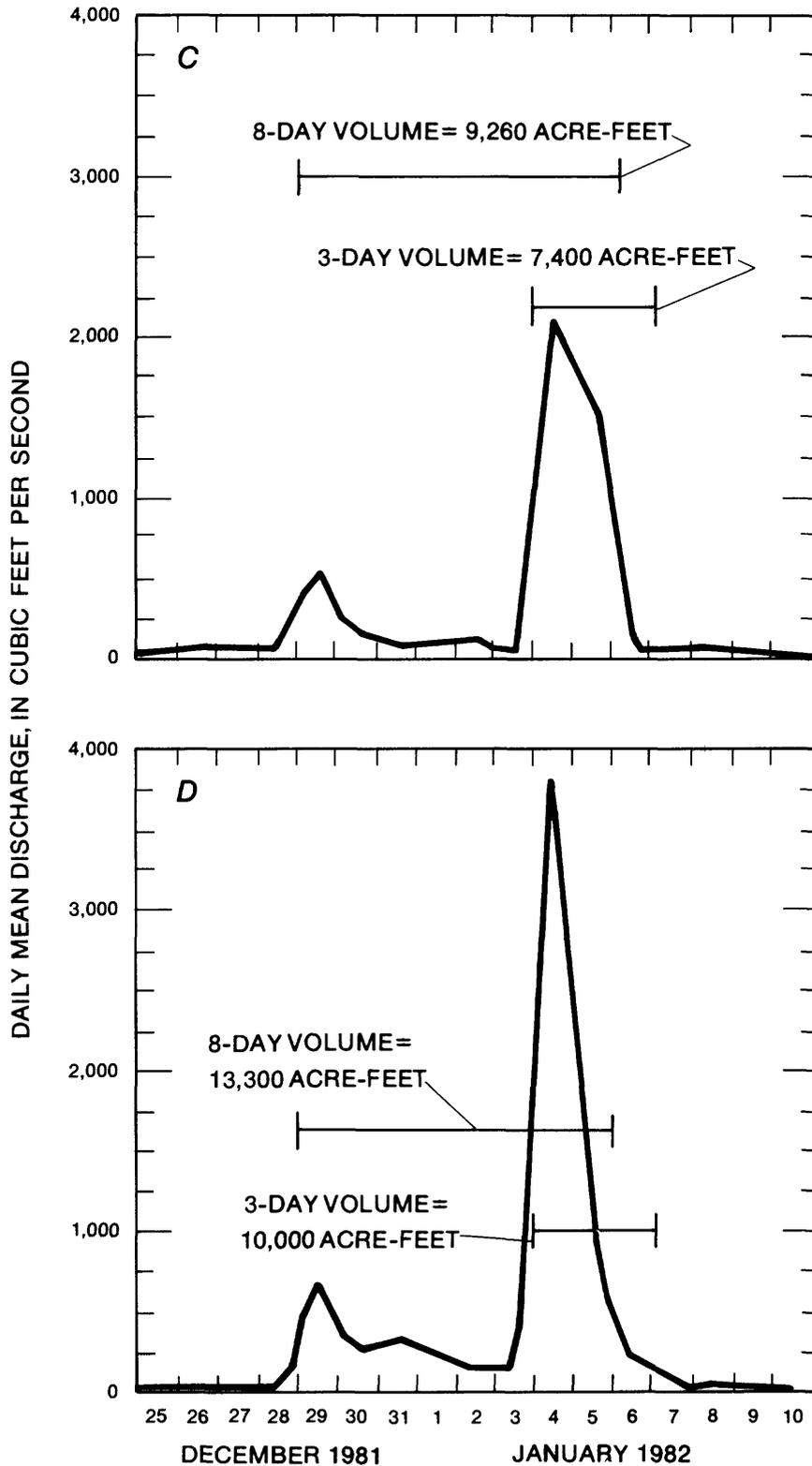


FIGURE 12.—Discharge at selected gaging stations in the San Francisco Bay area for the period December 25, 1981, to January 10, 1982 —Continued. C, San Ramon Creek at Walnut Creek (11183000). D, Corte Madera Creek at Ross (11460000).

There were 11 gaging stations where flood volumes were defined for both December 1955 and January 1982 floods. Volumes during the January 1982 flood for a duration of 3 days had smaller recurrence intervals than those for the December 1955 flood at 8 of these 11 stations (table 8). Recurrence intervals of volumes for the 8-day duration were less than those for the December 1955 flood at 10 of the 11 stations. The median recurrence intervals of the January 1982 flood volumes for durations of 1, 3, and 8 days are 18, 11, and 8 years, respectively. Recurrence intervals of flow volumes for these durations during the December 1955 flood are 13, 16, and 14 years, respectively, indicating that the total 1955 flood volume was slightly larger. Runoff volumes for the January 1982 flood with durations of 1, 3, and 8 days in the East and West Bay subareas generally had smaller recurrence intervals than streams in the Santa Cruz Mountains and North Bay subareas. In all four subareas in the San Francisco Bay area, flood peaks and 1-, 3-, and 8-day flow volumes for January 1982 and December 1955 floods were generally comparable.

The difference in flow characteristics between the two floods may be attributed to differences in antecedent conditions and total rainfall over the storm period; because of the absence of convective processes during the January 1982 storm, lower altitudes of the various basins were most affected by heavy rainfall.

SUMMARY

The meteorological setting of the January 1982 storm included two cold, damp storms from the Gulf of Alaska on January 1 and 3. Concurrently, a wave-cyclone system that originated over the tropics near Hawaii moved westward and stalled along the central California coast for 24 hours on January 3. Merging of these two frontal systems produced rain, which began early on January 3 over the San Francisco Bay area and ended in the early morning of January 5. Total duration of the storm was about 35 hours. Near record amounts of rain fell--about 16 inches in the Santa Cruz Mountains and 8 inches in the North Bay subarea. Precipitable water at the time of peak rainfall intensity was less than 70 percent of the observed maximum of record. As such, climatic conditions might occur in the bay area in general, and in the central California Coast Ranges in particular, that could increase storm rainfall above those levels recorded during the January 1982 storm. At many stations in the San Francisco Bay area, antecedent rainfall during the months October-December 1981 was twice that of normal, which contributed to the severity of flooding during the January 1982 storm. Much of the heavier rainfall was in the lower foothills up to altitudes of 700 feet, rather than near the ridges at altitudes of about 2,700 feet. The lower layer of moist air moving inland had a stable atmospheric structure; this vertically suppressed layer moved parallel to and around the mountains.

In the San Francisco Bay area, runoff for the season beginning October 1, 1981, was generally greater than normal by the end of November 1981, and subsequent storm runoff exceeded normal through the end of December; by this time the soil mantle was thoroughly saturated. Peak flows, unit peak runoff, and flow volumes for durations of 1, 3, and 8 days were used to describe the magnitude and frequency of the flood. For many streams, the January 1982 flood was

the largest since December 1955. The unit peak runoff was as much as 927 (ft³/s)/mi², and the medians for streamflow-gaging stations in the Santa Cruz Mountains and North Bay subareas were the highest, 220 and 250 (ft³/s) /mi², respectively. On the basis of flood frequency, the median recurrence interval of the January 1982 peak at the 66 stations is 10 years; recurrence intervals range from 2 to more than 100 years.

For the 16 gaging stations where peak data were obtained for both December 1955 and January 1982, the median recurrence intervals are 11 years for the December 1955 peak and 17 years for the January 1982 peak. However, the recurrence interval of the January peak is equal to or less than the December 1955 flood at 10 of the 16 sites. In terms of flood volumes for durations of 1, 3, and 8 days, the median recurrence intervals of the December 1955 flood are 13, 16, and 14 years; for the January 1982 flood they are 18, 11, and 8 years, respectively. The recurrence interval of the January 1982 flood is highest for streams in the Santa Cruz Mountains and East Bay subareas. These data indicate that the January 1982 flood was larger than the December 1955 flood for the peak and 1-day volume, reflecting the high intensity of rainfall for 1 day. Flood volumes for durations of 3 and 8 days indicate that, in terms of multiple-day volumes, the January 1982 flood was slightly smaller than the December 1955 flood.

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GLOSSARY

[A number of terms are defined below according to their use in this report. Where a word may be used either as a noun or verb only the noun form is defined]

- Acre-foot: The quantity of water required to cover 1 acre to a depth of 1 foot. It equals 43,560 cubic feet, 325,851 gallons, or 1,233 cubic meters.
- Convection: Vertical motions and mixing resulting when the atmosphere becomes thermodynamically unstable.
- Crest (of a flood): The point at which a stream stops rising. Crest is distinguished from "peak," which is used as the highest crest during a flood.
- Cubic feet per second: A rate of discharge. One cubic foot per second is equal to the discharge of a stream of rectangular cross section 1 foot wide and 1 foot deep, flowing at an average velocity of 1 foot per second.
- Dewpoint: The temperature at which the air becomes saturated when cooled under constant pressure and with constant water-vapor content.
- Discharge: The quantity of water, measured in cubic feet per second, passing a point during a given period of time.
- Drainage area: The area, measured in a horizontal plan, that is enclosed by a topographic divide. Drainage area is given in square miles.
- Flood: Any abnormally high streamflow.
- Flood peak: The highest value of the stage or discharge attained by a flood.
- Front: Boundary separating two different air masses.
- Gage height: The water-surface altitude referred to some arbitrary gage datum. Gage height is often used interchangeably with the more general term "stage", although gage height is more appropriate when used with a reading on a gage.
- Gaging station: A particular site on a stream, canal, lake, or reservoir where systematic observations of gage height or discharge are made.

Hydrograph: A graph showing gage height or stage, discharge, velocity, or other property of water with respect to time.

Lifted index: A stability index based on the difference, in degrees Celsius, between the observed 500-millibar temperature and the computed temperature that a parcel of air characterized by mean temperature and dewpoint of the 50-millibar thick surface layer would have if it were lifted from 25 millibars above the surface to 500 millibars.

Millibar: A pressure unit, equivalent to 1,000 dynes per square centimeter, convenient for reporting atmospheric pressure.

Miscellaneous site: A site where data pertaining only to a specific hydrologic event are obtained.

National Geodetic Vertical Datum of 1929 (NGVD of 1929): A geodetic datum derived from a general adjustment of the first-order level nets of both the United States and Canada, formerly called Sea Level Datum of 1929.

Peak: The highest crest during a flood.

Peak discharge: The highest instantaneous discharge occurring during a flood; measured in cubic feet per second. Also termed "maximum discharge."

Peak stage: The maximum height of a water surface above an established datum plane; same as peak gage height.

Precipitable water: The total atmospheric water vapor contained in a vertical column of unit cross-sectional area extending between any two specified surfaces: In this report, from ground surface up to the 500-millibar level.

Rainfall mass curve: A graph of the accumulated rainfall depth, plotted as an ordinate, against time or duration of storm, plotted as abscissa; the curve represents total precipitation depth throughout the storm.

Recurrence interval: As applied to flood events, recurrence interval is the average number of years over a long period of time within which a given flood peak will be equaled or exceeded once. For example, a 50-year flood discharge will be exceeded on the average of once in 50 years. The probability of the flood occurring is 0.02; there is a 2-percent chance that such a flood will occur in any given year.

Ridge: An elongated area of relatively high atmospheric pressure.

Runoff: That part of the precipitation that appears in streams. Measured as a volume, in acre-feet; or as a rate, in cubic feet per second.

Time of day: Expressed in 24-hour time. For example, 6 p.m. is expressed as 1800 hours Pacific standard time (P.s.t.).

Troposphere: That portion of the atmosphere from the Earth's surface to the tropopause--that is, the lowest 10 to 20 kilometers of the atmosphere.

Trough: An elongated area of relatively low atmospheric pressure.